THE RETURN OF INHIBITION IN VISUAL MARKING

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Abstract

Visual marking (Watson & Humphreys, 1997) and inhibition of return (IOR; Posner & Cohen, 1984) are thought to be distinct visual effects, despite similarities between the two in terms of their time course, their possible use of an inhibitory component, and advantages that each deliver to visual search in general. The present research provided a comparison of the visual marking and IOR effects through two experiments, the first examining patterns of individual differences in the effects, and the second utilizing a task which combined the IOR and visual marking paradigms. Overall, the results suggest that IOR and visual marking occur because of separate processes, but that the two effects may be complementary components in visual search, or related in some other way. The discussion centers on how the results contribute to understanding the similarities and differences between IOR and visual marking, the individual differences finding that some show a preference in using IOR over visual marking in search, and the proposal that IOR might account for a portion of the preview benefit in visual marking studies.

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The Return of Inhibition in Visual Marking

Visual search is an integral part of virtually every human behavior, yet despite the common thread of visual search connecting nearly all of our daily activities, the specific method by which the brain processes visual information in an on-going visual search is a matter of debate. Inhibition of return (IOR; Posner & Cohen, 1984) and visual marking (Watson & Humprheys, 1997) are two identified effects that are thought to play a role in visual search. Both are believed to make visual search more efficient by biasing search toward new locations, both are thought to use inhibition in some way, and both operate on similar time courses. Yet the general consensus, especially among visual marking researchers, is that the visual marking and IOR effects are fundamentally different.

Inhibition of return has traditionally been thought of as an attentional mechanism, produced when attention is captured by a peripheral sensory event, followed by inhibition of the previously attended area for up to 3 seconds. Posner and Cohen (1984) proposed that IOR exists as a mechanism to bias search toward new locations. A growing body of research has supported the idea that IOR-type effects exist in both attention and eye movement search, that the IOR-type effects act at specific locations, and that the IOR effects are limited in capacity (Klein, 1988; Klein & MacInnes, 1999; McCarley et al., 2003; Snyder & Kingstone; Takeda & Yagi, 2000).

Visual marking is also thought of as a mechanism which makes search more efficient, but through the inhibition of whole groups of items connected by a common time of onset (Jiang, Chun, & Marks, 2002b), rather than at individual item locations. The large number of items capable of being inhibited in visual marking is one reason given for its difference from IOR (Theeuwes, Kramer, & Atchley, 1998). Also, visual marking is thought to result from parallel search in the preview period (Olivers et al., 2002), as opposed to the serial search required to produce IOR (Klein, 1988). Finally, a number of studies have shown that the inhibition in visual marking tasks is different than the inhibition that would be expected in IOR tasks (Humprheys et al., 2004; Olivers et al., 2002; Watson Humphreys, 2000).

The current research was conducted to investigate the relationship between IOR and visual marking. The assumption was that the two effects are different, but may share one or more underlying mechanisms. Two experiments provided methods of comparison unique among the combined IOR and visual marking literature. The first was a correlation of basic IOR and visual marking measures among a group of subjects. The second was an experiment which combined the IOR and visual marking tasks in a way which placed the presumptive mechanisms in direct competition. The results generally supported the notion that the IOR and visual marking effects arise from different processes. Interactions between the effects suggest a relationship at some level, and the pattern of interferences suggested that visual marking was diminished more by IOR processes than IOR by visual marking. Examination of the individual differences in the two effects led to interesting results regarding the reliability of the effects, and the unexpected result that some individuals were more likely than others to use IOR instead of visual marking in the current tasks.

IOR and visual marking are reviewed separately below, followed by a more detailed description of the present research. The IOR review describes the initial IOR research, spatial and temporal properties of IOR, and research extending IOR to visual search. The visual marking review details the methodology used to measure visual marking and the theories of visual marking. Both sections highlight research on the inhibitory component of their respective effect, as well as existing research differentiating the two effects in some way.

Inhibition of Return

Posner and Cohen's original (1984) demonstration of IOR was accomplished with a simple cueing paradigm. The display consisted of a centrally located box flanked by a peripheral box on either side horizontally. During a trial, one of the two peripheral boxes brightened as a cue for 150 ms. A small bright target appeared later (at varying time intervals on different trials) in one of the three boxes. Subjects simply had to maintain central eye fixation, and press a button if the target was detected. The target usually appeared in the center, but occasionally appeared in one of the peripheral boxes. Response times varied depending on the time separating the onsets of the cue and target (the stimulus onset asynchrony, or SOA) and whether the target appeared in a cued or un-cued peripheral square. Responses were faster to targets appearing in the cued relative to the un-cued boxes at SOAs at or below 150 ms, but slower to targets appearing in cued relative to un-cued boxes at SOAs at about 300 ms and above. The latter, inhibitory effect, was also found with four possible cue positions and with dimming as well as brightening of peripheral box cues, but not when attention was directed by central arrow cues. These results led to the conclusion that both perceptual and attention systems were involved, in the sense that the inhibition occurred as a result of shifting attention to and from sensory changes at peripheral locations. The authors reasoned that such a mechanism would serve to encourage the sampling of new information from the environment by preventing attention from returning to previously attended locations.

Spatial Characteristics of IOR

The results of a number of studies have reflected the spatial effects of inhibition in IOR-like tasks. In an early example, Maylor and Hockey (1985, Exp 2) used a display employing a central fixation dot flanked on both sides by vertical rows of 7 dots. During each trial, the central dot in either the left or right row would brighten as a cue for 300 ms. The target followed, at long SOAs (i.e., greater than 700 ms), in any of the 14 peripheral locations. Target detection responses were slower on the cued than the un-cued side. On the cued side, responses were slowest when the target appeared at the cued location, and became faster as the distance between the cue and target increased. Thus, inhibition seemed greatest at the cued location and decreased with increasing distance from the cued location.

Recent studies have shown similar spatial effects of IOR. Pratt, Adam, and McAuliffe (1998) compared IOR in a task using the typical two-cue display to tasks in which 2, 4, or 6 peripheral cue locations were displayed. The slowest target detection responses were consistently to targets appearing in cued locations, with responses becoming faster with increasing distance between the target and cue locations. Bennett and Pratt (2001) tracked the gradient of inhibition with a 441 space virtual array of possible target locations. A cue could appear in the center of any of the four main quadrants. Target detection responses were always slowest in the cued quadrant and fastest in the quadrant opposite the cue, with intermediate RTs in the adjacent quadrants. These results consistently show that IOR acts with a spatial gradient, strongest at the cued location and decreasing outward from there.

Attentional Momentum vs. Spreading Inhibition

The spatial results in IOR studies (Bennett & Pratt, 2001; Maylor & Hockey, 1985; Pratt et al., 1998) are commonly thought of as *spreading inhibition*, or the idea that the strongest inhibition forms at the center of each attentional deployment, and subsequently spreads out in all directions, weakening as it travels from its epicenter. Pratt, Spalek, & Bradshaw (1999) proposed the *attentional momentum hypothesis* as an alternative to the spreading inhibition explanation for the spatial results of IOR experiments. According to the attentional momentum hypothesis, the IOR effect can be accounted for by attentional motion following the peripheral cue. Attention travels fastest in a straight line from cue to target location, resulting in the fastest responses whenever the target location is opposite the cue location. Adjustments in the direction of motion of attention result in RT costs, with the greatest cost coming in the case in which attention must stop, reverse course, and travel back to the cued location for target selection.

Pratt et al. (1999) supported the attentional momentum hypothesis with experiments with four cue locations surrounding a fixation point. The cue locations were spaced in an elongated diamond pattern, such that opposing locations were either of a long or short distance, while the short distance locations were spaced equally apart from the adjacent end locations as from the short opposing location. The spreading inhibition hypothesis would predict that RTs should be slowest at the cued location, and faster but the same at the short opposite and adjacent locations because they were equidistant, and fastest at long opposite locations because of weakening inhibition with further distance from the cue. Responses were actually successively faster at adjacent locations, then long opposite locations, then short opposite locations. These results support attentional momentum over spreading inhibition because of unequal RTs at the equidistant adjacent and short opposite locations, and because of the opposite pattern of RTs in the long and short opposing cue locations than would be expected due to spreading inhibition.

Snyder, Schmidt, and Kingstone (2001) responded with a series of experiments directly questioning the attentional momentum hypothesis of IOR. First, they showed that the opposite side facilitation effect was mostly eliminated when a central cue was included in the trial sequence after the peripheral cue and before the target appearance. Second, in a replication Pratt et al.'s (1999) research with long opposing and short opposing cue locations, Snyder et al. examined individual performance in their replication as well as Pratt et al.'s data. They found that the opposite side facilitation effects were being driven at only one of the four locations, whereas the same side inhibition effect was robust at all four locations. Also, more participants exhibited same side inhibition than opposite side facilitation. These results were used to argue against the attentional momentum hypothesis.

On balance, the evidence might favor the spreading inhibition over the attentional momentum hypothesis of IOR. However the answer to this question is not critical for the current research. It should be noted that the general decrease in RTs as the distance from the cued location increases could be important for the present research. Assuming that IOR operates at individual item locations, if IOR was operating in a visual marking task, then item locations attended during the preview period would be inhibited by the time the new items appeared, effectively eliminating previously attended portions of the display. Overall search efficiency would be increased by the effective reduction of the search display through the inhibition of the old item locations. Given the capacity limitation of IOR, the advantage gained through IOR of individual locations might be lost when set sizes increase beyond IORs capacity limits.

Temporal Characteristics of IOR

In addition to the spatial properties of IOR, the temporal properties of the phenomenon have been studied as well. A consensus of results has established a range of cue-target SOAs in which IOR appears, dependent upon the types of task and response involved. In Posner & Cohen’s (1984) simple detection task, facilitation was observed at SOAs less than 150 ms and inhibition at SOAs greater than 300 ms. Subsequent research has shown that IOR in eye movement data, shown by the saccadic response time (Briand, Larrison, and Sereno, 2000) can develop with an SOA as short as 200 ms. Lupiánez et al. (2001) conducted experiments comparing IOR in detection and discrimination tasks at short and long SOAs. They showed that IOR in detection tasks appears reliably by 400 ms, but discrimination tasks require a minimum SOA of 700 ms. The magnitude of IOR effects, in terms of RT differences between targets at cued and un-cued locations, was also greater in the detection response conditions.

Samuel and Kat (2003) composed a graphical meta-analysis of the time-course of IOR based on a number of IOR studies, which showed an average crossover from facilitation to inhibition at about 225 ms following the cue onset, with inhibition peaking at about 400 ms, and remaining at the peak magnitude for about 1.5 seconds, before gradually weakening to extinction by about 3.2 seconds after the cue onset. However, results depicting the end of IOR's duration were few, and thus the authors conducted experiments varying the SOA over long durations. They used a task with up to 8 locations examining the spatial effects of IOR over time (Exps 1 and 2). They showed that the IOR effect of longest RTs at the cued location was apparent with SOAs ranging from 400 ms to nearly 3000 ms. A spatial IOR effect of shorter RTs with increasing distance from the cued location was also observed, but only at SOAs from 400 ms to about 1200 ms. Thus, the time course of the centrally located inhibitory component and the spatially graded inhibition at near-by locations appear to have different time courses, with the spatially graded component diminishing by about 1200 ms following cue onset.

IOR in Visual Search

Finally, a number of studies have investigated the role of IOR in visual search tasks. Klein (1988) extended the notion of IOR to visual search by using a task in which a probe was presented 60 ms after target detection in either an efficient (C among Os) or an inefficient (O among Cs) search task. The key result was that probe responses were slower when the probe appeared at a former distractor locations than when probes appeared at previously empty locations, but only in the inefficient serial search condition. These results imply that an inhibition effect appears only during search that is difficult enough to require serial deployments of attention, and is associated with specific locations. Subsequent research (Wolfe & Pokorny, 1990) resulted in a failure to replicate Klein's original results. However, a number of recent studies have found IOR when the search display remains until the luminance probe appears, both with similar procedures to Klein's original task (Müller, & von Mühlenen, 2000; Takeda & Yagi, 2000), and with eye movement measures of a hidden picture search (Klein & MacInnes, 1999).

Converging evidence for the role of IOR in visual search has involved the use of rapid serial visual presentation (RSVP, Snyder & Kingstone, 2000; 2001). Snyder and Kingstone (2000) examined the number of separate locations capable of being inhibited in ongoing visual search by sequentially cueing placeholder boxes arranged into a circle surrounding a fixation cross. The authors found an IOR effect that was greatest when the cue preceded the target by one frame, and decreased linearly with each increasing frame of cue-target separation used in the study. The results suggest a mechanism that tags separate locations sequentially and inhibits attention from returning to the tagged locations, with decreasing inhibitory strength with increasing time after the cue. Overall, research on IOR in visual search is supportive of Posner and Cohen's (1984) suggestion that IOR may serve to facilitate visual search by preventing search from returning to previously attended locations.

Visual Marking

The research leading to the visual marking effect (Watson and Humphreys, 1997) was conducted to address questions regarding the target selection process in visual search. It was assumed that the target is somehow prioritized over surrounding distractors in order to be selected. Watson and Humphreys questioned whether items surrounding the target in visual search are also de-prioritized as part of the visual search process. The results of their experiments led them to conclude that surrounding distractors in visual search are de-prioritized through a goal-driven inhibitory process. They labeled this process visual marking, and concluded that it was a unique effect which could not be attributed to IOR or other known effects. Ensuing research has largely upheld the notion that visual marking is a unique effect in visual search, although there are disagreements as to the mechanisms underlying the marking effect (Donk and Theeuwes, 2001; 2003; Jiang, Chun, & Marks, 2002b; Peterson, Belopolsky, & Kramer, 2003). The following review is intended to cover the basic research leading to the marking effect. Alternative theories of visual marking will be highlighted, although the emphasis will be on research supporting inhibitory accounts of marking, especially those which purport to differentiate visual marking from IOR.

Visual Marking Methodology

The most general way of describing the empirical visual marking effect is as a search advantage in a *preview* condition compared to a non-preview search condition. In a typical preview condition, a sub-set of items (the *old* items) are displayed for some duration (typically 1000 ms), after which the remainder of search items (the *new* items), including the target, are added to the display. Visual marking is usually gauged in terms of search efficiency, which is calculated through RTs to targets appearing in displays of varying numbers of distractors. In general, RTs increase as more items are added to the display (Atkinson, Holmgren, & Juola, 1969). Search efficiency is characterized statistically by the *search slope*, defined as the increase in RT in milliseconds for every item added to the display (ms/item). Steep search slopes reflect difficult search conditions requiring serial inspection of display items, whereas shallow search slopes reflect search in which the target is located without the need to search each item in the display (Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1998). The *preview benefit* in visual marking is reflected by a shallower search slope in the preview condition than in a non-preview search condition.

In their original research defining the visual marking effect, Watson and Humphreys (1997, Exp 1) used a conjunction search task as a baseline of comparison for the preview condition. Participants searched for a blue *H* target among blue *A* and green *H* distractors. Trials randomly contained from 2 to 16 total items, and participants made a speeded target detection response. The preview condition was identical except that half the items (the green ones) were presented first for 1000 ms, after which the remaining (blue) items, including the target when present, were added to the display. Search slopes in the baseline condition averaged 26 and 48 ms/item for correct target present and absent responses, respectively, compared to 16 and 22 ms/item for correct target present and absent responses in the preview condition. The authors concluded that search was more efficient in the preview condition because participants were able to visually mark, or de-prioritize the previously viewed (old) items, and search through only the new items when they appeared.

Theeuwes et al. (1998) replicated the visual marking effect using a task eliminating the color difference between the old and new item sets, while also providing a second measure of the preview benefit in visual marking. The task was to detect the presence of an *H* appearing among other letters of the alphabet. All stimuli were white appearing on a gray background. In the preview condition the old and new set sizes were varied independently, such that 5, 10, or 15 old items appeared in the preview display for 1000 ms, followed by the addition of 5, 10, or 15 new items. An all-items control condition was included to examine search with total set sizes of 10, 20, and 30 items. A preview benefit was evident based on shallower search slopes in the preview condition (with total set sizes of 10, 20, and 30) than in the all-items condition, indicating that a color difference between old and new items was not required for the preview benefit to occur. Within the preview condition, RTs increased as the number of new display items increased, but did not vary as a function of the number of old display items. The result that search was not affected by the number of old items was seen as further evidence that the previewed items were de-prioritized and not searched when the new items appeared. Thus, the *independent manipulation* technique can be used to define the preview benefit in visual marking as an increase in RTs as the number of new items is increased, coupled with a lack of an RT effect as a function of old item set-sizes.

A third method of measuring the preview benefit in visual marking was provided by Jiang, Chun, & Marks (2002a), whose research further explored the differential effects that the old and new item set sizes contribute to the preview benefit observed in visual marking studies. The authors argued that varying the old and new item set sizes independently, as Theeuwes et al. (1998) had done, was a better method of measuring visual marking than basing search efficiency measures on total item set sizes because using the total set size search slopes combines any unique effects of old and new items. In cases in which marking is shown using total items to calculate search efficiencies, one can only assume that it was the old items that were marked and not searched. Examining old and new set-size effects separately allows the investigation of any unique effects of old and new item sets.

Jiang et al. (2002a) extended the independent manipulation technique by adding an invalid preview condition as a baseline of comparison. In their experiments, the stimuli were all identical in color, and subjects searched for a left or right rotated *T* among rotated *L* distractors, responding to the direction of target rotation. The typical (valid) preview condition was compared to an invalid preview condition in which the old items moved to random new locations simultaneously with the addition of the new items, forcing subjects to search through all items in the display once the target appeared. The preview benefit was then measured through comparison of search performance in the valid and invalid preview conditions. A preview benefit was observed in terms of a more efficient search slope in the valid than the invalid preview condition as a function of old item set sizes, supporting the notion that old items were de-prioritized and not searched when the new items were added.

Visual Marking Theories

Three theoretical views have been put forth to account for the preview benefit in visual marking, each emphasizing a different aspect of the visual marking effect. First, Watson & Humphreys (1997) suggested an active inhibition account, in which the visual marking effect is hypothesized to derive from active, goal driven inhibition of the previewed items in the search task. A second account of the marking effect is the luminance onset account (Donk & Theeuwes, 2001; 2003) in which prioritization of new search elements is thought to arise from automatic attention to the luminance onsets of new items, with little or no dependence on the preview of old items. A third view of visual marking emphasizes the temporal information associated with the onsets of the preview and final display item groups (the temporal segregation hypothesis, Jiang et al., 2002b). The following sub-sections will address each theory, along with the research on which each theory was originally based.

Watson and Humphreys (1997) based their suggestion of an active-inhibition account of visual marking on the results of a series of experiments conducted to define the effect and rule out alternative explanations for the observed preview benefit. The basic effect was shown in Exp 1 (described earlier), and extended in Exp's 2 and 3. The authors showed in Exp 2 that eye movements were not required during the preview display in order to produce the visual marking effect. In Exp 3 when the SOA between the onsets of the preview and final display was varied, a minimum of 400 ms SOA was required to produce the preview benefit.

Experiments 4-6 (Watson & Humphreys, 1997) were conducted to address whether IOR was producing the preview benefit. In Exp 4 the old items were presented as partial straight-line figure-8's during the 1000 ms preview period, and in Exp 5 a complete figure 8 was presented at each old item location during the preview period. In both cases the old items changed into *H*s when the new blue items were added, either by adding (Exp 4) or offsetting (Exp 5) line segments. Both of these manipulations eliminated the visual marking effect, indicating that participants were not able to exclude old items from the search whenever the old items underwent a luminance change as the new items were added. The authors reasoned that if visual marking was due to IOR then previously illuminated locations should be inhibited. It follows from this reasoning that a phenomenon destroyed under these conditions could not be due to IOR.

In Exp 6 (Watson & Humphreys, 1997) a 250 ms inter-stimulus interval (ISI) was introduced during the preview period to provide a different way of comparing visual marking to IOR. The thinking was that if attention was first captured by the onset of the old items and then withdrawn when the old items disappeared, then IOR should be operating at the old item locations upon the appearance of the new items (and reappearance of the old items). However including the ISI also eliminated the marking effect, a result which the authors suggested was further evidence that IOR was not operable in visual marking.

Donk and Theeuwes (2001; 2003) have argued that the reason that subjects search only through the new items is that attention is captured automatically by the abrupt onset of the new items, and that previewing a sub-set of the display has little to do with the preview benefit. They have proposed an onset account of marking, suggesting that the preview benefit observed in visual marking research is due to the prioritization of new items through attention to abrupt onsets rather than the de-prioritization of old items through inhibition. They supported these suggestions with two sets of experiments, each using a different approach, but both yielding results which highlight the contribution of attention to the new items to the visual marking effect.

In the first set of experiments supporting the abrupt onset account of visual marking (Donk & Theeuwes, 2001), abrupt onsets were defined as a luminance increase. The preview benefit was eliminated when all items were presented at the same luminance level as the background (Exp 1). Manipulating luminance levels of the old and new items separately showed that an abrupt luminance onset among the new items, but not the old items, was required to produce the visual marking effect.

In a second set of experiments (2003), the target could appear either as often or twice as often among the old set of items, thus manipulating the expectation, and presumably the attentional focus, of which set of display items to attend to (note that a target appearing in an old item location took the place of an old item through an equiluminant color change when the new items were added). Regardless of the probability that the target would appear with the old items, visual marking was eliminated when the target appeared among the old items, but was observed when the target appeared among the new items. The authors argued that since marking was observed when the target appeared among the new items despite no explicit incentive to attend to the new items, this was an indication that marking depends more on the bottom-up, stimulus-driven properties of the on-setting new items than on intentional de-prioritization of the previewed items. Taken together, these are the strongest arguments for a bottom-up account of the marking effect, although the authors concede that their results do not entirely rule out the possibility that inhibition of old objects may still occur in some experiments.

Jiang et al. (2002b) proposed the *temporal segregation hypothesis* to account for the preview benefit in visual marking. According to this account, the visual marking process starts with a grouping of the old and new search displays via a temporal component, followed by a spatial deployment of attention to the behaviorally relevant group containing the target. They supported their argument with an experiment (Exp 3) showing that marking could occur following a luminance change among old items as long as there was a temporal separation between the luminance change and the onset of the new items, a result which was counter to a number of experiments showing that marking was eliminated by luminance shifts at old locations simultaneous with new item onset (Jiang et al. 2002b Exps 1 & 2; Watson & Humphreys, 1997, Exps 4 & 5). Jiang et al. (2002b) argued that the luminance change occurring simultaneously with the addition of the new items eliminated the marking effect because it destroyed the ability to separate the groups temporally. In Exp 4 (Jiang et al., 2002b) the behavioral relevance of new and old item sets was reversed by *always* including the target with the preview set. The preview duration in this experiment was only 150 ms, which, according to the authors, was long enough to support temporal asynchrony between old and new item display onsets, but short enough to prevent target identification prior to the onset of the new items. The results were the opposite of the typical marking results, matching the reversal in expectation of which display the target would appear in (there were no effects of increased new item set sizes, indicating that the new items were de-prioritized). The authors suggested that their results support the notion that both the presence of temporally distinct onsets of old and new item sets (Exps 1-3) and the top-down knowledge of which display to attend to and which display to ignore (Exp 4) are critical in producing the visual marking effect.

Research Differentiating Inhibition in Visual Marking and IOR

There have been several empirical approaches in visual marking research with evidence converging on accounts of visual marking in which inhibition of the old items plays a part. However most of this research provides evidence suggesting that the inhibition in visual marking is different than IOR. One approach has been to measure responses to probe dots appearing on old items in either a preview or baseline condition, at various times during a trial, to gauge inhibitory processing at individual locations (Humphreys, Stalmann, & Olivers, 2004; Watson & Humphreys, 2000). A second approach has been to create deliberate IOR-like search in the preview display of visual marking trials, by including search tasks in both displays on some trials (Olivers, Humprheys, Heinke, & Cooper, 2002). A third method involves comparing visual marking and IOR based on their temporal similarities (Kunar, Humphreys, & Smith, 2003; Land et al., 2006; Pratt & McAuliffe, 2002; Watson & Humphreys, 1997). These research examples all support the view that inhibition of the old items is an essential mechanism underlying visual marking, although they do not all agree on the nature of the inhibition or its relationship to inhibition in IOR.

In the first example of probe dot research in visual marking (Watson and Humphreys, 2000), on 75% of trials the task was to search for a blue *H* target among blue *A* and green *H* distractors. On 25% of trials the task was to search for a probe dot that appeared briefly in the bottom half of one of an old (green) or new (blue) distractor stimuli in either the preview or control condition. Probe detection accuracy did not differ according to the type of display for probes appearing on new items, but there was a performance cost for probes appearing on an old item following a preview display, compared to the standard non-preview search condition. In contrast, there were no probe detection differences whenever the experiment was repeated with target detection task removed so that probe detection was the only task (Exp 2). The authors suggested that the results of Exp 2 ruled out forward masking and attentional prioritization to new items as explanations for the results of Exp 1, and that the combined results indicated that visual marking is an inhibitory process that can be voluntarily applied or withheld.

Later research with a probe-dot technique (Humphreys et al., 2004) provided a clearer look into both facilitation and inhibition in visual marking. The search task was for a red vertical rectangle target among green vertical and red horizontal rectangle distractors appearing on a blue background grid. On half of preview trials (Exp 2) a probe dot appeared for 50 ms, either within an old or new rectangle or in a neutral location, and either preceding or following the new items' onset by 200 ms. Subjects always made a speeded response to the presence or absence of a red vertical target, and on prompted trials made an un-speeded response to the presence or absence of the probe. Probe-detection costs at old compared to neutral locations, both when the probe appeared 200 ms before and 200 ms after the new items were added, supported an inhibition hypothesis of marking. Inhibited responses to probes appearing before the new items onset was a critical finding because it showed that inhibitory process were in place before the abrupt onset of the new items could have any affect on visual marking.

Olivers et al. (2002) conducted research comparing IOR with visual marking on the grounds that they use different types of search processes during the time preceding the target appearance (i.e., the cue in IOR and the preview display in visual marking). The type of search during the preview display was manipulated by using a double search task, in which targets appeared in both the preview and final displays, on some trials. In different blocks of trials, the majority of trials were either double search trials or visual marking trials (with a target only in the final display). In both cases on a minority of random trials the task could be switched from double to single search, or vice versa. The logic was that, regardless of validity, in the double search trials subjects would actively search the preview display and in visual marking trials subjects would ignore the preview display. The results showed a cost in search efficiency in the invalid double search condition compared to the valid visual marking condition, indicating that deliberate search of the old items, as is the case in search leading to IOR, eliminated the preview benefit. The presence of visual marking that is dependent on parallel or passive search of the preview display, and eliminated by serial or deliberate search of the preview display, supports the notion that IOR and visual marking are based on different processes.

A third method of comparing inhibition in visual marking and IOR is through manipulations of the timing of the onsets of the preview and final displays in visual marking trials, based on the similarity in the timing sequences of the two effects. Watson and Humphreys (1997; Exp 6) ruled out the possibility that visual marking could be a product of IOR because the preview benefit was eliminated by presenting the preview display for 750 ms followed by a 250 ms blank screen, a timing sequence that, according to Watson and Humphreys, was more typical of an IOR task than a visual marking task. Other researchers have also varied the timing of events in visual marking tasks, with varying results (Kunar et al., 2003; Pratt & McAuliffe, 2002).

Kunar et al. (2003) introduced what they called a *top-up* preview display, in which the old items onset for 450 ms, offset for 250 ms, then onset again for 150 ms before the new items were added. Marking was found in this condition but destroyed when the same display was used with only a 150 ms preview display. The authors used this technique because of previous findings that a blank screen immediately preceding the final display eliminated visual marking (Kunar, Humphreys, Smith, & Watson, 2003, Exp 2; Watson & Humphreys, 1997, Exp 6). The finding of visual marking in a condition in which the preview display disappeared for some duration is supportive of a visual marking account in which processing of the old items plays a critical role in the effect.

Pratt and McAuliffe (2002) disagreed with the timing sequence used by Watson and Humphreys (1997) to argue that IOR and visual marking were not related. Pratt and McAuliffe showed that IOR was present in a simple two-location cueing task with ISIs of 500 and 750 ms, (following cue onset durations of 500 ms and 250 ms respectively), but not with the 250 ms ISI used by Watson & Humphreys (1997, Exp 6). This result suggests that IOR may not have been at work in Watson and Humpreys' research because they did not use the correct timing sequence to evoke IOR. In Exps 2 and 3 (Pratt & McAullife, 2002) a more traditional visual marking task was tested with a non-typical blank screen ISI of 500 ms as part of the 1000 ms preview display. In Exp 2 the task was a single feature search for a white *H* among white *A*s, resulting in a preview benefit in search. However when color was added to the display, making the task a conjunction search, the marking effect was eliminated when a 500 ms ISI was used (Exp 3), but was present in the typical visual marking paradigm when the 1000 ms preview display did not include a blank screen ISI (Exp 4). The authors did not suggest an explanation for the survival of the preview benefit over a 500 ms ISI in Exp 2 but not in Exp 3. The result of Exp 2 suggests that inhibitory processes at the old item locations could survive the offset of the old items, an action reminiscent of IOR results in which inhibitory costs are seen in responses occurring some time after the offset of the cue.

The Current Research: Comparing Visual Marking and IOR

Visual marking and IOR share several common traits; both are thought to be mechanisms which can lead to more efficient visual search, both are believed to operate because of inhibition directed to certain locations, and both operate on similar time courses. However despite the similarities between visual marking and IOR, a majority of the visual marking literature represents the view that the inhibitory processes in visual marking are fundamentally different than those in IOR. The present research was conducted to compare IOR and visual marking with two experiments designed to determine if the effects are related in some way. The first experiment was designed to examine a possible correlation between the two effects, using simple, basic tasks known to elicit IOR and visual marking. The second experiment utilized a novel task intended to place the pre-target processes in the two paradigms in direct competition.

The assumption in Exp 1 was that if IOR and visual marking are related in some way, then similar individual difference patterns between IOR and visual marking would be evident by a reliable correlation. On the other hand, no evidence of a relationship would indicate that IOR and visual marking are independent processes. The IOR and visual marking tasks were designed to yield "pure measures" of their respective effects, by mirroring tasks known to produce robust effects at the group level. The IOR task (Exp 1a) consisted of a typical two location cueing paradigm, and included a central cue after the peripheral cue in order to prevent opposite side facilitation effects (Snyder et al., 2001) as well as to replicate Bergers (2006; see below) IOR reliability results with a central cue. The IOR task is illustrated in Fig 1, and typical IOR results are illustrated in Fig 2. The calculation of IOR magnitude for each participant consisted of subtracting the RT to detect a target appearing in the un-cued peripheral square from the RT to detect a target appearing in the cued peripheral square.

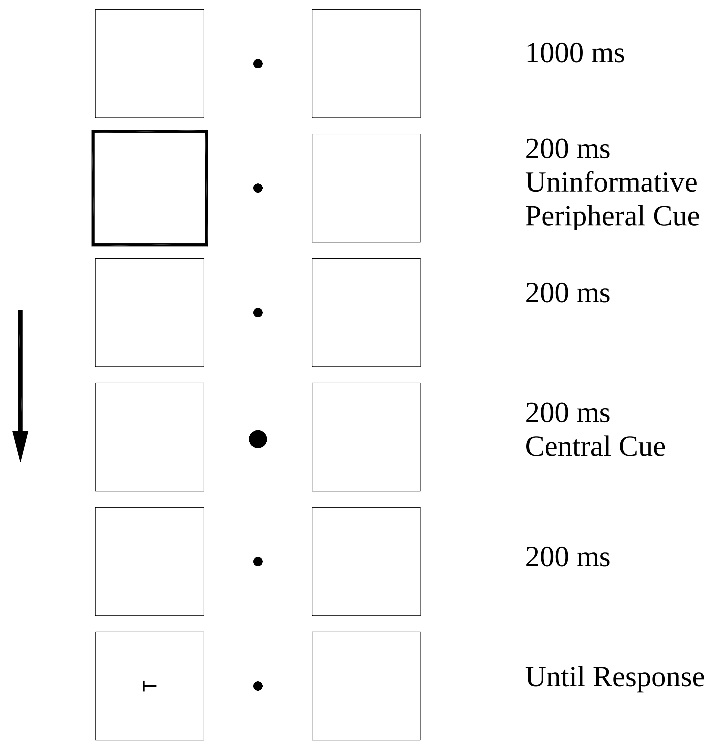

Figure 1. Illustration of an IOR trial used in Exp 1a. The target, shown on the cued (valid) side, could appear equally as often on the un-cued (invalid) side.

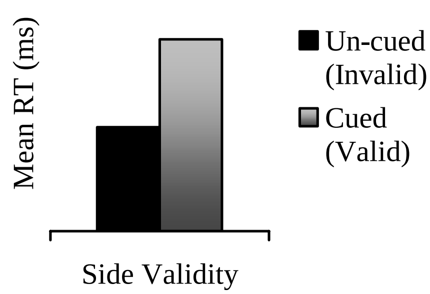

Figure 2. A cost in target detection time for targets appearing on the valid side relative to targets appearing on the invalid side is the typical result in an IOR task when the SOA between the cue and target onsets is in the range of 300 to 3000 ms.

Visual marking was measured (Exp 1b) by comparing valid and invalid search slopes plotted as a function of the number of old items (Jiang et al., 2002a). Fig 3 illustrates the visual marking task used in the present research. During invalid trials the old items moved to random new locations on the final display, concurrent with the addition of the new items. This has the effect of eliminating visual marking, forcing the search to proceed through the old as well as the new items, causing an increase in search as the number of old items increase. When the old items remain in the same location throughout the trial the visual marking effect is observed in terms of limited or no increase in search times as a function of the number of old items. Fig 4 illustrates the theoretical example of “perfect” marking, in which the valid search slope is flat. The calculation of visual marking magnitude for each participant was determined by subtracting the search slope in the valid condition from the search slope in the invalid condition.

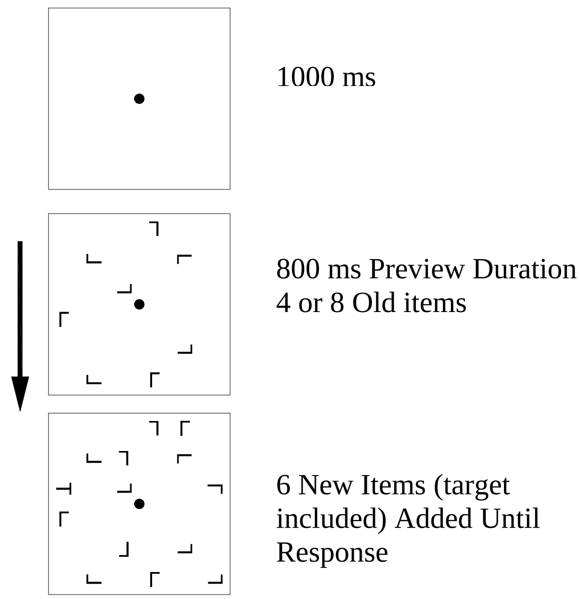

Figure 3. Illustration of a visual marking trial in Exp 1b. In the valid old items condition (shown) the old items remained in place. In the invalid old items condition, the old items moved to random new locations when the new items were added in the final display.

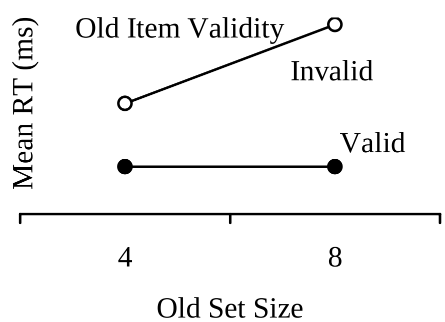

Figure 4. In the theoretical case of "perfect" visual marking, in the valid condition the old items are excluded from the search once the new items are added. In the invalid condition the inclusion of the old items in the search is demonstrated by increasing RTs as the number of old items increases.

The examination of IOR and visual marking at the individual differences level, as opposed to the group level, represents a relatively untested methodology in these paradigms. In spite of the large body of literature surrounding these two effects, there are only a handful of studies assessing individual differences in the effects, and only one that directly addresses reliability. Berger (2006), noting the robust IOR effect typically found at the group level, conducted research to determine if IOR could be used as a reliable measure of attentional orienting at the individual level. A typical location cueing paradigm was used, with a non-informative cue on one side followed by a target on the same or the opposite side. When no central cue followed the initial peripheral cue, there was no significant correlation between individual IOR magnitudes between multiple IOR sessions or between eyes when IOR was examined monocularly. However when a central cue appeared after the peripheral cue and before the target IOR appeared somewhat more reliable, with a significant split-half correlation (odd vs. even blocks) of participants' IOR scores (Exp 2a; $r = .64$, $p < .01$), and a significant relationship between participants' IOR scores between eyes (Exp 2b; $r = .37$, $p < .05$). The author suggested that the central cue led participants to adopt a more consistent strategy in completing the task, thus leading to more stable measurement of IOR.

Given the limited research on the reliability of individual differences in IOR and visual marking, the reliability of both effects was assessed in Exp 1. Exp's 1a (IOR) and 1b (visual marking) each included a *reliability* variable, with two conditions crossed factorially with the other variable(s), and all trials presented in random order in a single session. This design allowed the IOR and visual marking data to be collected in one session each. Note that since both IOR and visual marking are derived functions calculated from mean RTs in multiple conditions, assessing reliability from an odd-even trial split is impossible if conditions are presented by randomizing the trial order in a single block of trials. Finally, the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) was administered to each participant in Exp 1 as a measure of general cognitive ability. The K-BIT is composed of vocabulary and matrices sub-tests, intended to measure crystallized and fluid intelligence, respectively. If IOR and visual marking were shown to be reliable and correlated, the K-BIT scores could be used as control measures to show that the relationship of interest was not due to a third factor such as general ability or intelligence. If no relationship between IOR and visual marking was found, differences in correlations with K-BIT scores could be helpful in determining possible differences between the effects.

In Exp 2, a novel task was employed which combined the visual marking and IOR paradigms with the intent of placing inhibitory processes from the two in direct competition. This was accomplished by presenting the visual marking stimuli within the peripheral squares used as cues in the IOR task, and cueing one of the peripheral squares during the visual marking preview period. These IOR-visual marking *combination* trials are illustrated in Fig 5. In addition to the combination trials, two other conditions were tested in Exp 2, using the same basic display. In a *visual marking control* condition, the task was identical to the combination trials except that the peripheral cue was not included. This was to verify that visual marking was operating in the divided visual field display without the peripheral (IOR) cue. In an *IOR response* condition, the task was identical to the comparison trials except that in the final display the old items disappeared, and only the target appeared in the center of either the cued or un-cued peripheral square, as in the IOR trials of Exp 1b. All three conditions were presented in a single session of randomized trial order. If IOR and visual marking occur because of distinct and independent mechanisms, then both effects should be exhibited in the IOR-visual marking comparison condition. If the two effects interact in some way, then this should be apparent by diminished visual marking effects in the IOR-visual marking combination condition compared to the visual marking control condition, and by diminished effects in the IOR response condition compared to the basic IOR task in Exp 1a.

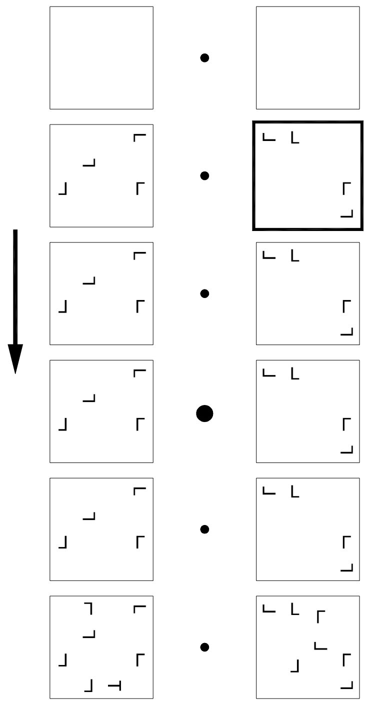

Figure 5. Illustration of an IOR-visual marking combination trial in Exp 2. Old items either remained in place (as shown) or moved to random new locations in the final display. The target appeared with the new items in the final display, on either the cued or un-cued side.

General Method

Participants. A total of 32 undergraduate students at the University of Kansas participated. The group consisted of 9 males and 23 females, and the average age was 19.5 years. The participants were recruited through the psychology subject pool, with no restrictions placed on the recruiting process. Two of the participants were non-native English speakers, and experienced difficulty with the vocabulary portion of the K-BIT. Therefore, these two were dropped from the sample, and all results are reported with the remaining 30 participants.

Apparatus and Stimuli. For the visual search (i.e., IOR and visual marking) tasks, stimulus presentation, response timing, and data collection were controlled using a 1600/66 Power Macintosh computer with a 17-in monitor. The stimulus set consisted of *L*s and backward *L*s presented in four possible orientations, with a target *T* appearing in one of four possible orientations. All stimuli were black, and the background was gray. The distractor *L*s and target *T* were presented in 14 pt. Helvetica font (about 0.4 deg visual angle for the letter height). Lighting in the room was dimmed during the visual search tasks. Participants completed the visual search tasks from an unrestrained viewing distance of about 60 cm.

The K-BIT (Kaufman & Kaufman, 1990) consists of verbal and non-verbal subtests of intelligence, intended to capture crystallized and fluid capabilities in a brief measure, and usually used as a screening device. The verbal component of the K-BIT included expressive vocabulary items in which participants named pictured objects, and definitions, in which participants were given a clue and a partially filled in word, and were to complete the partially filled in word as the answer. The non-verbal component required participants to reason through visual puzzles, choosing the answer from a multiple choice list of possibilities. All responses were hand-scored as correct or incorrect. Each sub-test score was later converted to a standardized score, from which a composite standardized score was derived. The K-BIT is not a speeded test, though participants are urged to move on if an answer is not apparent within about 30 seconds. The time required to complete both sub-tests in the current study ranged from about 20 to 30 minutes.

Procedure. The visual search task was to detect the target *T*. A response time (RT) was recorded for each trial, based on the time between the appearance of the target and the pressing of the space bar. Catch trials with no target were included in all conditions as a way to encourage attentional focus and decrease anticipatory responses. Trials were coded as errors, and accompanied by auditory beeps, if a response was recorded on a catch trial or if no response was recorded on a target trial within a specified time limit following the target appearance. In all visual search tasks, participants were instructed to respond as quickly as possible if the target was detected, while also limiting errors.

A target detection task was chosen, as opposed to a discrimination task, because detection tasks are more common in IOR research (e.g., Posner & Cohen, 1984), and have been shown to elicit greater IOR effects than discrimination tasks (Lupianez et al., 2001). Additionally, a simpler task might offset the increased difficulty of the visual marking experiment created by the divided visual field (Exp 2). Visual marking has been shown with both detection (e.g., Watson & Humprheys, 1997) and discrimination (e.g., Jiang et al., 2002a) responses. An SOA of 800 ms was chosen in all visual search tasks (i.e., the time separating the cue and target onsets in the IOR task, and the preview and final search displays in the visual marking task), corresponding to time courses in which IOR and visual marking are known to be fully operating as measured with detection responses (Humphreys et al., 2004; Lupianez et al., 2001).

Each participant completed all experiments in a single session lasting 75-90 minutes, and earned course credits for their participation. Exps 1a and 1b were administered first, in a counterbalanced order across participants. The K-BIT was administered between the visual search tasks of Exps 1 and 2. All participants completed Exp 2 last.

Experiment 1a; Inhibition of Return

The purpose of this experiment was to demonstrate the IOR effect among a group of participants and obtain an individual measure of IOR from each participant in the task. The individual IOR measures were obtained to gauge the reliability of individual differences in IOR, as well as to explore the relationship between IOR and visual marking.

Apparatus and Stimuli. The basic IOR display consisted of a central fixation dot flanked by a black square on each side (see Fig 1). The fixation dot was a filled black circle measuring 0.3 deg visual angle in diameter. The peripheral squares measured 4.7 deg visual angle per side, and were spaced evenly to the left and right of the fixation dot, with about 9.2 deg visual angle separating the centers of the squares. The "brightening" of the fixation dot as a central cue was accomplished by increasing the diameter of the filled black dot to 0.45 deg visual angle. The "brightening" of a square as a peripheral cue was accomplished by increasing the line thickness from one to four pixels, effectively increasing the outer dimensions of the square while maintaining the inside dimensions.

Procedure and design. In each trial, the basic display (fixation dot and peripheral squares) was shown for 1000 ms, after which one of the squares brightened as a cue for 200 ms. After a 200 ms delay, the central fixation dot was brightened as a cue for 200 ms, followed by another 200 ms delay, and then the target *T* appeared in the center of either the cued or un-cued square. Participants were instructed to ignore peripheral events, and to respond as quickly and accurately as possible if the target was detected in the final display. There was a 1500 ms time limit for response, after which a double beep sounded if a response had not been recorded on a trial in which a target was present. The next trial began 1500 ms after a response was recorded. A break was given after every 48 trials.

The variable of interest was side cue validity, or whether the target appeared on the same (valid) or different (invalid) side as the peripheral cue. Additionally, reliability was coded as a separate variable with two conditions. Thus, the design was a 2 (cue side validity) x 2 (reliability) within-subjects factorial design. There were 20 trials in each cell of the design, for a total of 80 trials. The target appeared equally as often on each side in each cell of the design. Trials were presented in random order, along with 16 catch trials in which no target was present. The 96 experimental trials were preceded by 12 practice trials.

Results and Discussion. Error rates were low, with 0.04% of trials coded as an error because a response was not given when a target was present, and 1.5% of trials coded as an error because a response was made on a catch trial. In this and all remaining experiments, RTs less than 150 ms were considered anticipatory responses and coded as outliers. The remaining RTs were then subjected to an iterative outlier removal procedure, in which RTs greater than twice the mean in each cell of the design for each participant were coded as outliers and removed from the analysis (Peterson, Belopolsky, & Kramer, 2003). In Exp 1a this procedure resulted in 0.71% of trials coded as outliers and removed from the analysis.

Mean RTs for the trials not coded as errors or outliers are shown in Fig 6A. The mean RT for detecting targets appearing on the same (valid) side as a peripheral cue was 387 ms, compared to 352 ms for detecting targets appearing on the opposite (invalid) side as the peripheral cue. A 2 (cue side validity) x 2 (reliability) repeated measures analysis of variance (ANOVA) indicated that the greater RT for the valid side cue was significant [$F(1,29) = 123.8$, $p < .001$]. There was no difference or interaction in mean RTs according to the reliability variable.

Individual IOR magnitudes were calculated by subtracting the invalid side cue RT from the valid side cue RT for each participant, in each reliability condition. The variability of IOR scores can be seen in Fig 6B. When collapsed across reliability, the mean IOR magnitude was 35 ms, with individual IOR scores ranging from 3 ms to 84 ms, and a standard deviation of 17 ms. The correlation of individual IOR magnitudes in the two reliability conditions was significant, *Pearson' r* = .403, *p* = .027, indicating what might be considered moderate reliability of the IOR effect.

The results of Exp 1a showed the expected IOR effect at the group level, in terms of a cost in detecting the target appearing on the cued relative to the un-cued side. In terms of the reliability of individual differences in IOR, the moderate correlation between individual IOR magnitudes in the two reliability conditions is similar to the findings of Berger (2006; reliabilities of .37 to .64) when a central cue was included in her IOR task. Whereas no test is perfectly reliable, most psychological tests have reliabilities above .70. The moderate reliability of IOR found by Berger, and replicated in the current Exp 1a, could serve as a caution to those considering the use of an IOR task to screen individual attentional orienting ability.

A) B)

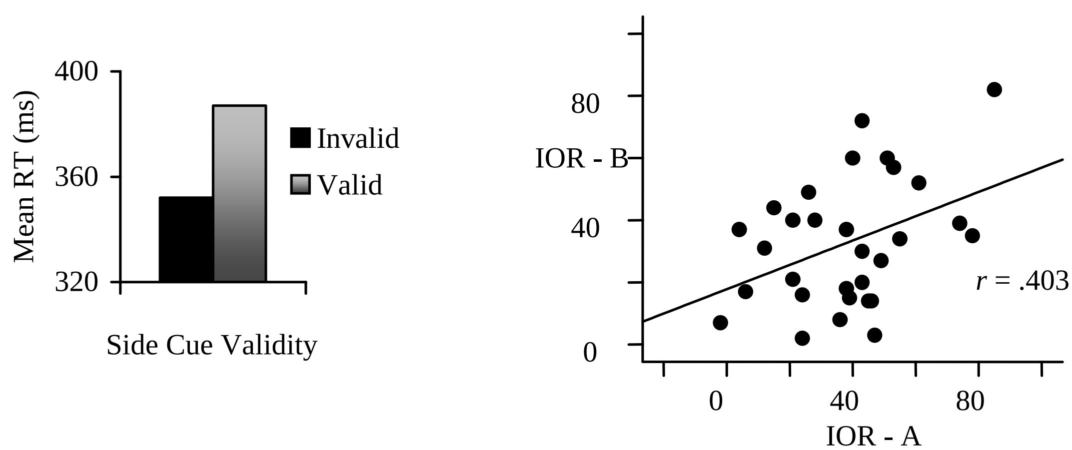

Figure 6. Results of IOR Exp 1a. A) The presence of IOR at the group level is indicated by a significant cost in mean RT to detect targets on the valid cue side compared to the invalid cue side. B) The scatter-plot of individual IOR magnitudes in the two reliability conditions shows the variability and moderate reliability of individual IOR magnitudes.

Experiment 1b; Visual Marking

The purpose of this experiment was to demonstrate the visual marking effect among a group of participants and obtain an individual measure of visual marking from each participant in the task. The individual visual marking measures were obtained to gauge the reliability of individual differences in visual marking, as well to explore the relationship between visual marking and IOR.

Apparatus and Stimuli. The basic visual marking display consisted of a virtual 7 x 7 array outlined with a black border, measuring about 6.4 degrees on each side (see Fig 3). The distractors and target on each trial appeared in random locations within this array, except for the center location, which always contained a fixation dot.

Procedure and Design. In each trial, the central fixation dot and array outline appeared for 1000 ms, after which either four or eight items were added for the preview duration of 1000 ms. Following the preview, six new items were added, including the target. In the valid old items condition, the old items remained in place when the new items are added. In the invalid old items condition, the old items moved to random new locations when the new items were added. Participants were instructed to maintain central fixation and ignore the items in the preview period, and to respond as quickly and accurately as possible if the target was detected in the final display. There was a 2000 ms time limit for response, after which a double beep sounded if a response had not been recorded on a trial in which a target was present.

The next trial began 1500 ms after a response was recorded. A break was given after every 48 trials.

The design was a 2 (old item set size) x 2 (old item validity) x 2 (reliability) within-subjects factorial design, with 20 trials per cell for a total of 160 trials, presented randomly along with 32 catch trials in which no target appeared. The total of 192 experimental trials was preceded by 18 practice trials.

Results and Discussion. The average error rate for trials in which a target was present but no response was recorded was 1.9%, and 6.7% for trials in which a response was recorded on a catch trial with no target. An additional 2.5% of trials were coded as outliers and removed from the analysis based on the outlier procedure described for Exp 1a. .

The mean RTs of the trials not coded as errors or outliers are shown in Fig7A. Visual marking is apparent in the data by a shallower search slope according to old item set size in the valid old items than in the invalid old items condition. A 2 (old item set size) x 2 (old item validity) x 2 (reliability) ANOVA confirmed the presence of visual marking with a significant Old Item Set Size x Old Item Validity interaction, $F(1,29) = 11.0$, $p = .002$. There was no effect of or interaction according to the reliability variable. Thus, on average, in the valid old items condition participants were able to exclude the old items from the search, presumably due to the visual marking of the old items. When the old items shifted to new locations at the onset of the new items, marking was eliminated, forcing the search to proceed through the old items as well as the new items for the target, as evidenced by the increasing search times with old item set sizes.

Individual visual marking magnitudes were calculated by subtracting the valid search slope from the invalid search slope for each participant, in each reliability condition. The variability of visual marking magnitudes can be seen in Fig 7B. Collapsed across reliability, the mean invalid search slope was 23 ms/item, and the mean valid search slope was 8 ms/item. Thus, there was on average a 15 ms/item visual marking effect in the group. Individual visual marking magnitudes varied from -31 ms/item to 61 ms/item, and the standard deviation was 24 ms/item. The correlation of individual visual marking magnitudes between the two reliability conditions was not significant, *Pearson' r* = -.033, *ns*. This indicates that the visual marking effect was not reliable at the individual level, despite the presence of the effect, on average, in the group as a whole.

The finding in Experiment 1B of a significant visual marking effect at the group level combined with the unreliability of the effect at the individual level is perhaps surprising. This result suggests that participants were using visual marking to find the target only some of the time, or to varying degrees across trials. Inspection of the visual marking scatter plot (Fig 7B) shows that, if individual marking is defined by a positive slope difference between the valid and invalid search slopes, only nine subjects showed marking consistently across the entire set if trials, while four never used marking, and the remaining participants used marking inconsistently across trials. In contrast, although there was variability in IOR magnitudes across participants in Experiment 1a, virtually all participants showed an IOR effect (defined by a positive RT difference between valid and invalid side cues).

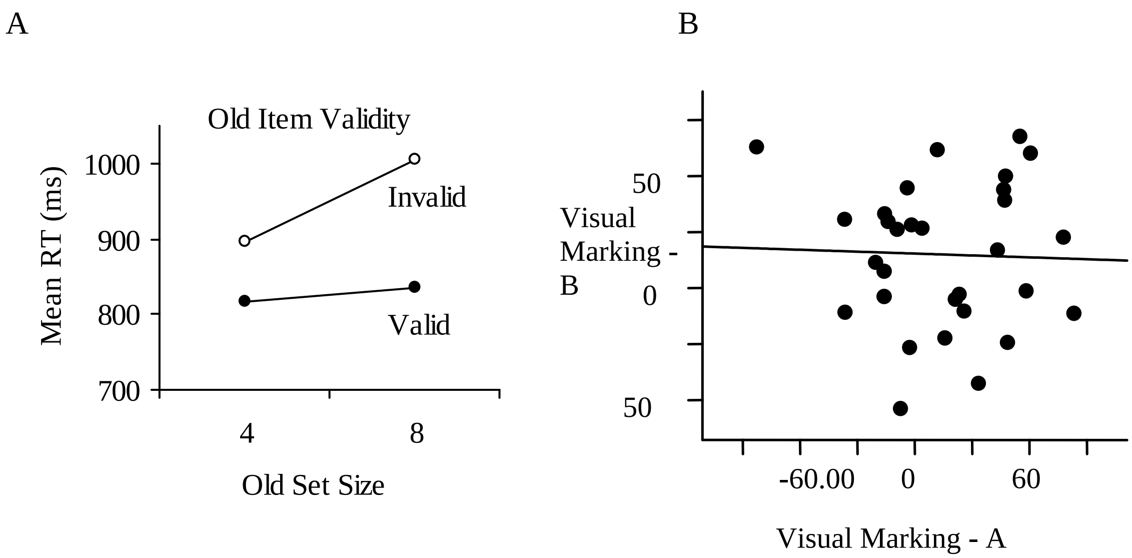

Figure 7. Results of visual marking Exp 1b. A) Visual marking is present among the group, as indicated by the interaction of search slopes. B) Visual marking at the individual level was not reliable.

In order to further explore the appearance that some people are consistent visual markers and some are not, a between-subjects *visual marking ability* variable was created by splitting the group at the median visual marking magnitude (10 ms/item difference between valid and invalid old item search slopes collapsed across the reliability condition). These groups will be referred to as *high markers* and *low markers*. Note that each of these groups contained approximately half of the subjects that could be labeled as inconsistent visual markers. Thus, with n = 15 in each group, the correlation between the two reliability conditions was not significant in either the high marking group or the low marking group. Comparing IOR magnitudes between the two visual marking groups revealed that both groups showed the IOR effect; a mixed ANOVA on the IOR data from Exp 1a showed no significant effects or interactions with the between-subjects visual marking ability variable. However, as seen in Fig 8, when the reliability of IOR was compared between the two visual marking groups, IOR was not reliable among the high markers (*Pearson's* $r = .017$, *ns*), but was reliable in the low markers ($r = .684$, $p = .005$). This result suggests that participants least likely to show consistent visual marking are most likely to consistently exhibit the IOR effect.

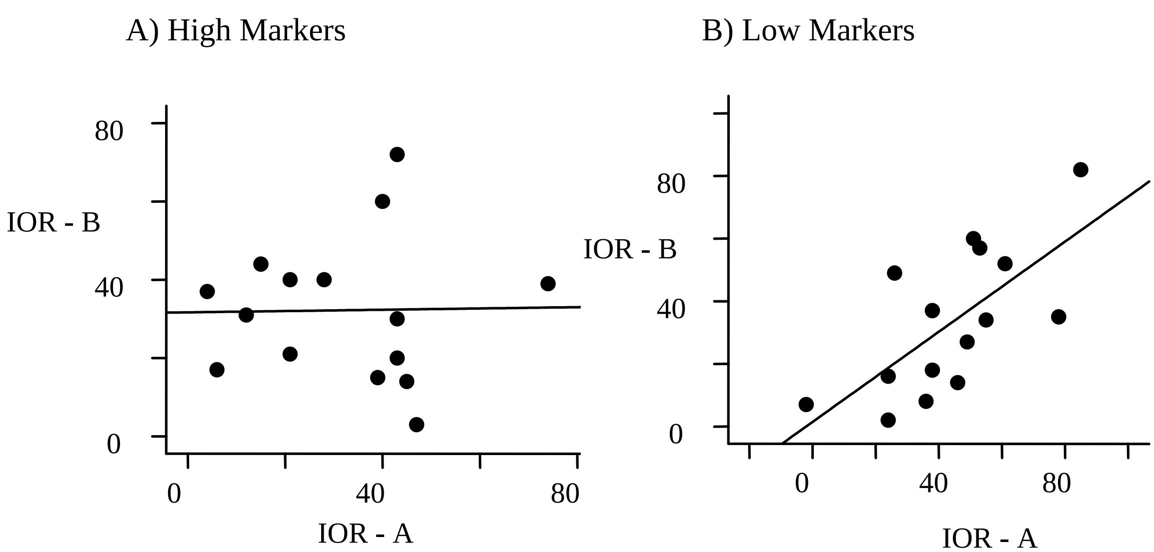

Figure 8. IOR was not reliable among the high marking group ($r = .017$, *ns*), but was reliable among the low marking group ($r = .684$, $p = .005$).

Finally, the mean RTs from Exp 1b were entered into a mixed ANOVA to determine if there were any differences in how the high marking and low marking groups handled search in the valid and invalid old items conditions. Whereas the statistical indicator of visual marking is the Old Set Size x Old Item Validity interaction, the only condition in which visual marking is operating is the when the old items remain in place throughout the trial. The obvious statistical visual marking difference between the marking ability groups can be seen by the difference in the critical interactions between the two groups [i.e., the Old Item Validity x Old Set Size x Marking Ability interaction, $F(1,28) = 50.3$, $p < .001$, see Fig 9]. The marking effect was obvious in the high marking group, but absent in the low marking group [the Old Item Validity x Old Item Set Size interactions were $F(1,14) = 58.2$, $p < .001$, and $F(1,14) = 2.09$, $p = .170$, respectively]. The high markers appeared more efficient in valid old item search (2 ms/item) than the low markers (8 ms/item), though this difference did not reach significance, $F(1,28) = 3.5$, $p = .074$. In contrast, there was a striking difference in how the participants in the different groups handled the target search in the invalid old items condition. For the low markers, search efficiency in the invalid old items condition was not different than search efficiency in the valid condition, as shown by the absence of an Old Item Set Size x Old Item Validity interaction in the low markers group. It was as if the low markers were exhibiting a marking-type effect even when the old items moved to random new locations on the final display. In contrast, marking was obviously eliminated in the invalid old items condition for the high markers. The interaction of Old Set Size x Marking Ability on invalid old items was significant, $F(1,28) = 25.9$, $p < .001$. Thus, the difference between the two groups was driven more by how they handled the search when the old items shifted suddenly to random new locations than their actual visual marking ability.

A) High Markers B) Low Markers

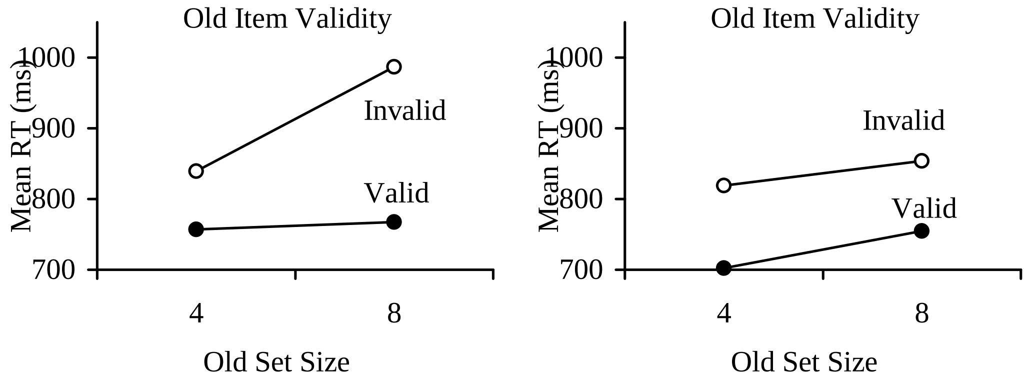

Figure 9. Visual marking Exp 1b results according to marking ability. The search slope interaction shows the strong marking effect in the high marking group. Diminished marking in the low marking group is driven more by efficient search in the invalid old items condition than by inefficient search in the valid condition.

The finding that the low marking group was effectively marking the invalid old items was surprising. One possible explanation is that the high markers used visual marking in the task, and the low markers used IOR in the task. The IOR reliability difference between the groups suggests that the low markers more consistently exhibit the IOR effect. A widely held assumption in the visual marking literature is that visual marking operates in a parallel fashion on groups of items (e.g., Olivers et al., 2002) partly because of the large sets of old items capable of being marked (up to 15, Theeuwes et al., 1998). In contrast, IOR is thought to act at individual locations, and is known to be limited in capacity (4 to 6 items, Klein &

MacInnes, 1999; McCarley, Wang, Kramer, Irwin, & Peterson, 2003; Snyder & Kingstone, 2000). Because of the small old set sizes used in the current study (4 or 8), the low markers could be using IOR in the task. That is, they could have been inhibiting the initially attended old item locations in the display, even after those items moved in the invalid old items condition, leading to more efficient search in the effectively reduced display size.

Correlation of visual marking and IOR

In the overall group of participants, the correlation between visual marking and IOR was not significant (r = -.150, *ns*). Regarding the K-BIT data, the mean standardize score on the verbal component was 102.4, with scores ranging from 91 to 115, with a standard deviation of 7.5. For the non-verbal component M = 103.3, SD = 8.1, with scores ranging from 87 to 128, and for the composite scores M = 103.1, SD = 7.3, with scores ranging from 88 to 120. There were no significant correlations between any of the K-BIT scores and either visual marking or IOR. Although the relationships were not significant, the correlations between the composite K-BIT score and IOR (r = -.240, *ns*) and between the composite K-BIT score and visual marking (r = .109, *ns*) were nevertheless in opposite directions. These correlations seem to diverge between the two marking groups; in the low marking group, the correlation between the composite K-BIT score and IOR was r = -.396, *ns*, compared to r = .301, *ns*, for the correlation between the composite K-BIT score and visual marking. The comparative correlations in the high marking group were r = -.039, *ns*, and r = .099, *ns*, respectively. A t-test for differences between correlations in non-independent groups (Williams, 1959), showed that the two correlations were not different for the group as a whole [$t(27) = -1.24$, *ns*]. The difference between correlations approached significance for the low marking group [$t(12) = -1.86$, $p = .07$, for a two-tailed test]. The inverse relationships of IQ with IOR and visual marking corroborate the notion that IOR and visual marking are different effects. The divergence of this inverse relationship between the two visual marking groups could be taken as further evidence that the groups are different in how they apply IOR and visual marking during visual search.

Experiment 2;Combining the Visual Marking and IOR Paradigms

The purpose of Exp 2 was to compare the IOR and visual marking effects in a task designed to place pre-target processes in the two paradigms in direct competition. The visual marking and IOR results in the trials combining the two paradigms in Exp 2, compared to the visual marking and IOR control trials, was intended to shed light on the possible relationship of IOR and visual marking. The Exp 1 result that some participants might be using IOR instead of or in addition to visual marking was unexpected. This result would be supported by evidence in Exp 2 showing that the IOR and visual marking effects interfere with each other, and by continued differences between the performance of the high and low marking groups.

Apparatus and Stimuli. The basic display, consisting of central fixation dot flanked by two peripheral boxes (see Fig 5), was identical in size and parameters to the basic display used in the IOR experiment (Exp 1a). Each square contained a virtual 5 x 5 array in which visual marking stimuli could appear. In the IOR response trials, the target always appeared in the central location of one of the peripheral squares.

Procedure and Design. In the IOR-visual marking combination trials, the basic display appeared for 1000 ms, after which either 4 or 8 old items were added, split evenly between the two peripheral squares, for the preview duration of 800 ms. One of the peripheral squares brightened as a cue for the first 200 ms of the preview period, followed by a 200 ms delay, a 200 ms fixation cue, another 200 ms delay, and finally the addition of 8 new items, split evenly between sides, with the target on either the cued or the un-cued side. The old items either remained in place or moved to random new locations when the new items were added. The visual marking control and IOR response trials were identical except that in the visual marking control there was no peripheral cue, and in the IOR response condition there was no old item validity, as the old items all disappeared on the final display, replaced by the appearance of a single target in the center of the cued or un-cued square. Participants were instructed to maintain central fixation and ignore the items in the preview period, and to respond as quickly and accurately as possible if the target was detected in the final display. There was a 2500 ms time limit for response, after which a double beep sounded if a response had not been recorded on a trial in which a target was present. The next trial began 1500 ms after a response was recorded. A break was given after every 48 trials.

The design for the IOR-visual marking comparison trials was a 2 (old set size) x 2 (old item validity) x 2 (cue side validity) within-subjects factorial design, with 20 trials per cell for a total of 160 trials. The design for the visual marking control condition was a 2 (old set size) x 2 (old item validity) within-subjects factorial, with 20 trials per cell for a total of 80 trials. The design for the IOR response condition was a 2 (old item set size) x 2 (cue side validity) within-subjects factorial, with 20 trials per cell for a total of 80 trials. The 320 trials in the three combined conditions were presented randomly in a single block of trials, along with 64 catch trials in which no target was present. The total of 384 experimental trials was preceded by 16 practice trials. A break was given after every 48 trials.

Results and Discussion. Participants did not record a response when a target was present on 0.4% of trials, and responded on a catch trial when no target was present on 6.1% of trials. An additional 2.6% of trials were coded as outliers and removed from the analysis based on the outlier procedure described in Exp 1a.

The mean RTs from the remaining trials were analyzed with separate repeated measure ANOVAs for each of the three conditions in the experiment. First, in the visual making control condition, visual marking was apparent as indicated by a significant Old Set Size x Old Item Validity interaction, $F(1,29) = 59.2$, $p < .001$, see Fig 10. This result indicated visual marking was exhibited by the group in the divided visual field visual marking task without a peripheral cue included as part of the trial sequence.

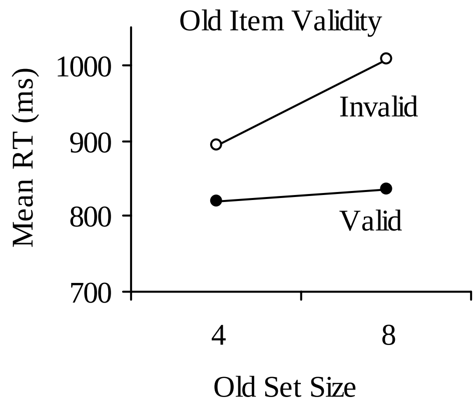

Figure 10. Results in the divided visual field visual marking control condition of Exp 2. Visual marking was operating, as indicated by the search slope interaction.

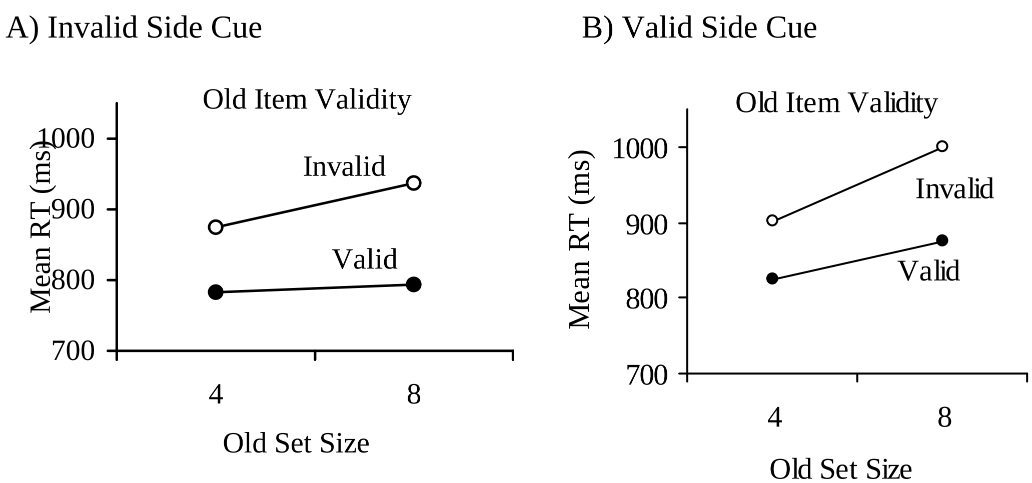

Figure 11. IOR-visual marking combination trials in Exp 2. An IOR effect was apparent because of the overall RT cost for targets appearing in a cued square. Visual marking was diminished in both side cue conditions; the search slope interaction did not reach significance in either condition.

The data from the IOR-visual marking combination trials are shown in Fig 11. Separate 2 x 2 ANOVAs showed that the Old Item Set Size x Old Item Validity interaction did not reach significance in either side cue validity condition [$F(1,29) = 2.37$, $p = .135$ and $F(1,29) = 1.9$, $p = .184$ for target appearance on the invalid and valid cue side, respectively] . Also, in a 3-way analysis of the overall data, side cue validity did not significantly interact with anything, but the Old Item Validity x Old Item Set Size interaction, with data collapsed across side cue validity, was significant [$F(1,29) = 4.8$, $p = .037$]. Thus, the visual marking effect was apparent overall, but eliminated when considered separately according to side cue validity, regardless of whether the target appeared on the cued or un-cued side. Regarding IOR, the main effect of side cue validity was significant, $F(1,29) = 19.5$, $p < .001$), with a greater mean RT to targets appearing on the cued side (899 ms) than for targets appearing on the un-cued side (844 ms), indicating a 55 ms IOR effect. The combined results from the IOR-visual marking combination trials seem to indicate that IOR was present regardless of visual marking, whereas the visual marking was apparent but suffered from the presence of IOR processes.

In the IOR response condition, there was a small (11 ms) but significant [$F(1,29) = 8.0$, $p = .008$] effect of cue side validity (see Fig 12). The number of old items preceding the target appearance did not affect or interact with cue side validity. The slower mean response (508 ms) when the target appeared on the valid cue side compared to the invalid cue side (497 ms) is indicative of IOR. The cost of the visual marking stimuli on the IOR effect can be seen by the different effect sizes when the IOR response condition of Exp 2 was compared with the IOR trials of Exp 1a, reflected in a significant Cue Side Validity x Experiment interaction, $F(1,29) = 15.1$,

p = .001. These results seem to indicate that the IOR effect was diminished when the old items disappeared as the target was onset in the final display.

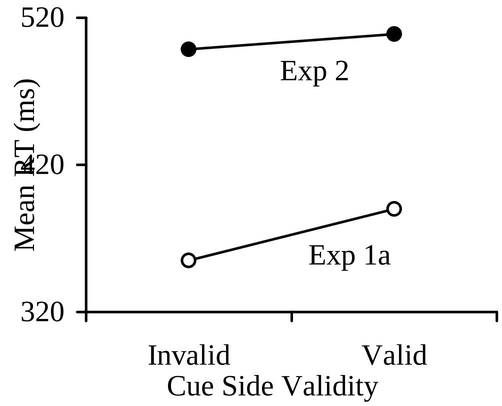

Figure 12. Results of the IOR response condition of Exp 2, compared to the IOR results of Exp 1a. The 11 ms effect in Exp 2 was significant, but smaller than the 35 ms effect in Exp 1a.

In order to further examine the notion from Exp 1 that the high and low marking groups differed in terms of whether and how much each used IOR in conjunction with visual marking in the current search, the above analyses were re-run with the marking ability variable from Exp 1b included as a between-subjects variable. In the visual marking control condition, the high markers appeared to maintain their better marking status, with significant marking shown by the Old Set Size x Old Item Validity interaction in the high marking group, $F(1,14) = 15.0$, p = .002, but not in the low marking group, $F(1,14) = 3.4$, p = .085. This result (see Fig 13) suggests that the visual marking ability division created by the results of Exp 1b was consistent with the marking behavior of these groups in the visual marking control condition of Exp 2.

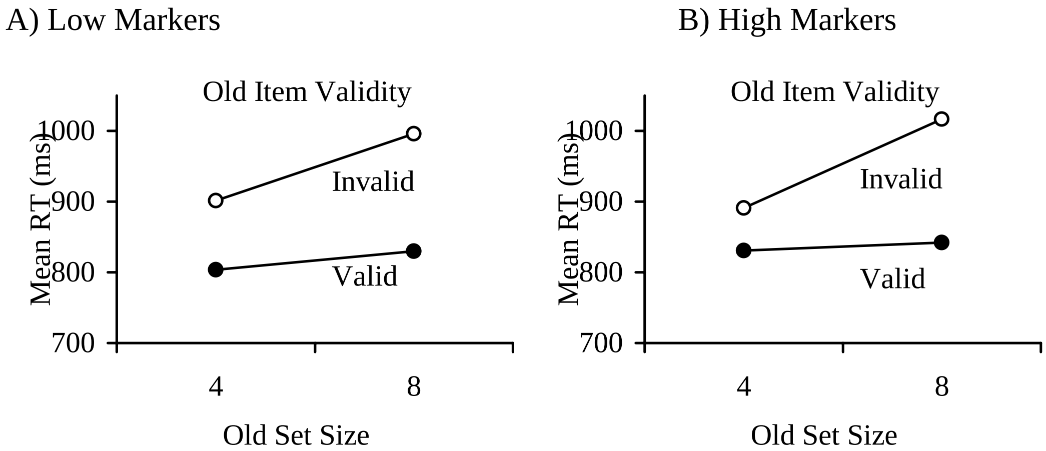

Figure 13. Separate results of the visual marking control condition of Exp 2, according to the marking ability variable created from Exp 1b. Visual marking was statistically evident only in the high markers group.

Figure 14 shows the IOR-visual marking combination trials for each of the marking ability groups defined in Exp 1b. An IOR effect was apparent for both groups in terms of greater overall RTs in valid side cue trials compared to invalid side cue trials, reflected by main effects of side cue validity in both the low marking group, $F(1,14) = 8.1$, $p = .013$, and the high marking group, $F(1,14) = 11.3$, $p < .005$. However, a visual marking effect was present only for the low marking group in the invalid side cue condition [Old Set Size x Old Item Validity interaction, $F(1,14) = 6.0$, $p = .028$]. Search appeared to be efficient whether the old items remained in place or moved to random new locations. When collapsed across the old item validity condition, search by the low marking group on the invalid side was the only case in which RTs did not increase significantly with old set size ($F < 1$). If the low markers more consistently used IOR in their search as suggested by the results of Exp

1, perhaps the IOR effect was operating on the invalid side for the low markers only. This could be explained by a broader, stronger, and/or a more consistent gradient of inhibition for the low markers. Thus, for all participants, attention was drawn to the valid side by the peripheral cue, with lingering inhibition of that side leading to greater overall RTs and diminished marking. On the invalid side, more efficient search exhibited by the low markers could be because for these subjects, attention was captured by the small number of old items (2 or 4) appearing in the invalid square, in addition to the valid peripheral cue.

Finally, Fig 15 shows the difference between high and low markers according to side cue validity in the IOR response condition. The overall IOR effect was actually driven by the low markers, as this group showed a significant side cue validity effect [$F(1,14) = 5.5$, $p = .035$], whereas the high markers did not [$F(1,14) = 2.6$, $p = .128$]. Additionally, only the low markers appeared to search efficiently when the target appeared on the invalid cue side (RTs did not increase significantly with old set size in any case, but $F < 1$ only for the low markers on the invalid cue side). This is the same response pattern shown by the low markers in the invalid side cue validity condition of the Exp 2 IOR-visual marking combination trials. The common trend of more efficient search for the low markers on the invalid side in both conditions of Exp 2 supports the notion that the low markers could have been inhibiting individual item locations on the invalid side of the display in addition to inhibiting the overall valid side following the valid peripheral cue.

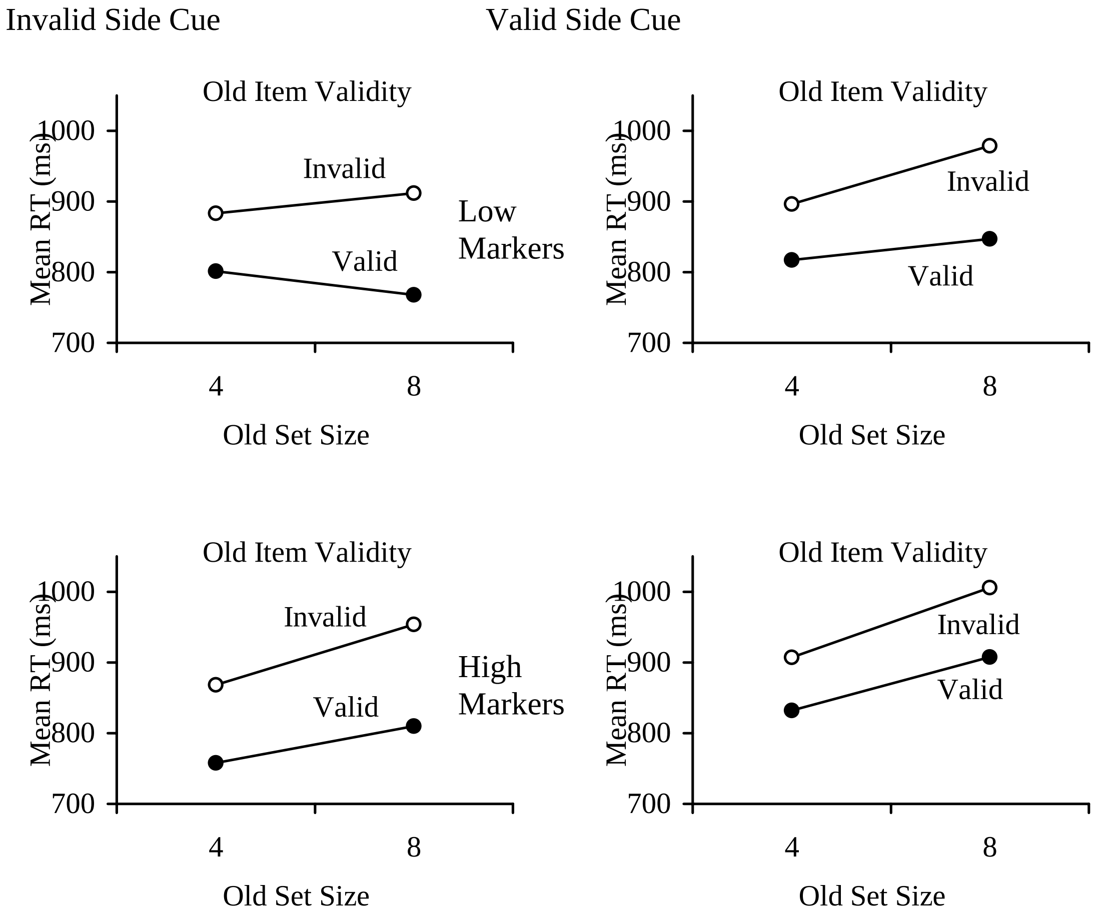

Figure 14. Comparison of high and low markers in the IOR-visual marking combination trials of Exp 2. Both groups showed an overall IOR effect, with greater overall RTs to targets appearing on the cued side. The most efficient search overall was by the low marking group, and only when the target appeared on the un-cued side.

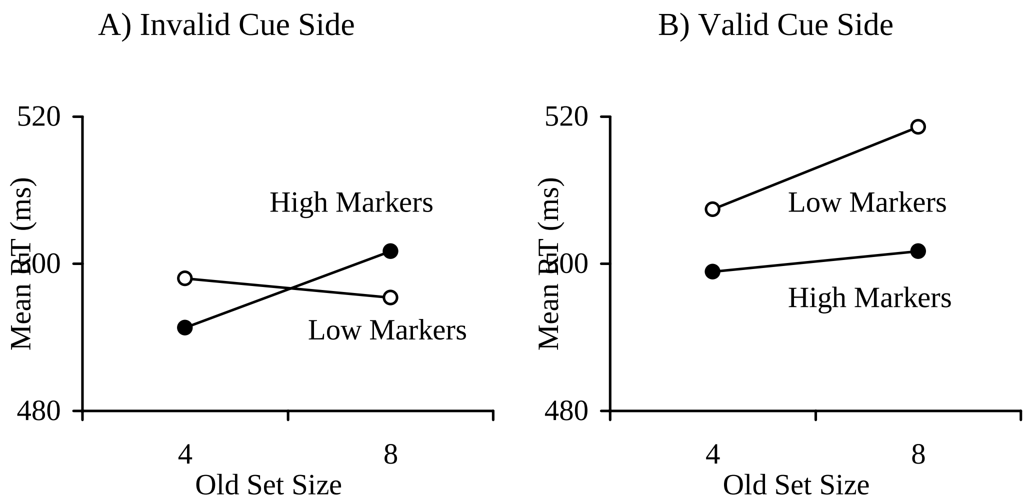

Figure 15. Comparison of high and low markers in the IOR response condition of Exp 2. IOR is present in both groups as indicated by the greater RTs when a target appeared on the cued side. The appearance of efficient search only for the low markers on the invalid side is similar to this groups' search behavior in the IOR-visual marking comparison trials of Exp 2 (see Fig 14).

Overall, the results of Exp 2 support the idea that IOR and visual marking are different effects. The question of how the two effects are different and/or how the two effects interact could probably be answered in more than one way. The proposition from Exp 1 that some participants use IOR to complete the visual marking task is one possibility, but was supported by a consistent pattern of differences between the high and low marking groups in Exp 2. First, in terms of diminished marking among the low markers in the visual marking control trials of Exp 2 and second, in the consistent pattern of differences between how the low and high markers handled search when the target appeared opposite the cued sied.

General Discussion

The present research was conducted in order to compare the IOR and visual marking effects using two experiments unique to these areas of research. The first experiment tested for the reliability of individual differences in each effect, and for a possible correlation between IOR and visual marking. The second experiment tested for effect differences using a task combing the typical IOR and visual marking experiments in such a way as to invoke both processes during the trial. The overall results suggested that IOR and visual marking are different processes, while interactions between IOR and visual marking and differing patterns of reliability offered clues to the nature of a possible relationship between the two effects which seem to complement each other in visual search. The following discussion details the key results from this research and outlines one possible explanation.

First, the combined results of Exps 1 and 2 showed that the IOR and visual marking effects result from what appear to be separate and perhaps complementary processes. The results of Exp 1 showed that the IOR effect can be considered moderately reliable at the individual level, but visual marking cannot. The discrepancy between the finding of visual marking at the group level, concurrent with the lack of consistent marking among individuals comprising the group, suggests that visual marking was applied as a search strategy either inconsistently or intermittently. Examination of the data in the IOR (Fig 6) and visual marking (Fig 7) tasks shows that all subjects effectively exhibited IOR, as defined by an RT cost for targets appearing on the valid cue side. In contrast, visual marking performance seemed divided, with some showing consistent visual marking, some never showing marking, and the majority showing marking some but not all of the time. Splitting the visual marking group into high and low marking groups, defined by a median split of individual marking magnitudes in Exp 1b, led to the unexpected finding that the low markers reliably exhibited IOR, whereas the high markers did not (see Fig 8). This result suggests that IOR and visual marking are complementary effects, and the tendency to use IOR over visual marking was consistent at the individual level in the present experiment. Also, the apparent inverse relationships of the IQ scores with IOR and visual marking supported the notion, suggested by the reliability results, that IOR and visual marking occur because of different processes.

In the IOR-visual marking combination trials of Exp 2, in which pre-target IOR and visual marking processes were competing, separate processes were evident by both IOR and visual marking effects in the data. IOR effects were shown consistently in terms of a cost in RTs when the target appeared on the cued side of the display, relative to the un-cued side. The valid side-cue RT cost was consistent across conditions and trials, and never interacted with other variables in the study. The visual marking effect seemed to be trying to exhibit itself, but was diminished by the side cues, with the critical interaction of search slopes not reaching significance when the target appeared in the cued or the un-cued side (Fig 11). However the Old Set Size x Old Item Validity interaction was significant when the data were collapsed across the side validity condition, suggesting that separate IOR and visual marking processes were both operating, though perhaps IOR was the dominant effect. That is, IOR was present regardless of visual marking, but the reverse was not true. Visual marking was shown statistically by the overall data, but it was diminished by the presence of IOR when considered at the separate array locations. Taken as a whole, the results of Exps 1 and 2 seem to support the notion that the IOR and visual marking effects result from separate processes.

If IOR and visual marking are assumed to be separate processes, this does not rule out the possibility that they may still be related in some way. The task in Exp 2 was designed to show how the IOR and visual marking effects might interact with each other when both were invoked during the pre-target display. Interference between the two effects was notable, and it might be helpful to think about them from the view of each effect respectively. First, from the perspective of IOR; as mentioned previously, the IOR effect was present in all experiments. As a basis for comparison, the IOR effect in Exp 1a, considered a pure IOR task, was 35 ms. The IOR effect for the same group of subjects was only 11 ms in the IOR response task of Exp 2, which was identical except for the inclusion of visual marking stimuli during the IOR cueing period (see Fig 12). The smaller IOR effect in Exp 2 was significant, but diminished, either due to the interference of processing the visual marking stimuli in the preview period, or perhaps because the off-setting old items simultaneous with the target appearance had the effect of re-setting or erasing lingering inhibitory effects from the peripheral cue. Nevertheless it is notable that the IOR effect prevailed in the IOR response condition of Exp 2, because the same cannot be said about visual marking. From the visual marking perspective, visual marking was present in the divided visual field control condition of Exp 2 (Fig 10), but comparatively diminished, and statistically absent when considered separately at search arrays that were either cued or un-cued during the preview period (Fig 11). Thus, visual marking was diminished at both the cued and the un-cued side by the presence of the IOR cue in the preview period. Finally, there was a strong IOR-type effect embedded within the visual marking data of the IOR-visual marking combination trials of Exp 2. The side cue validity variable did not interact with old set size or old item validity, and when collapsed across these other variables, there was a 55 ms overall cost of RT detection on the cued side relative to the un-cued side, a strong IOR effect (Fig 11). Overall, the interferences shown by Exp 2 suggest that IOR and visual marking may share common processes or resources, although the exact nature of any shared process or resources were not apparent in the current study. On balance, it seems that the IOR effect was exhibited more strongly, or perhaps more automatically, than the visual marking effect. The visual marking effect suffered more from the presence of IOR than the IOR effect suffered from the presence of visual marking. Therefore, one explanation might be that the visual marking draws, at least in part, on IOR processes.

The data thus far reveal a possible scenario in which IOR and visual marking are separate processes, but that visual marking might utilize IOR in some way, and that the participants differ in their use of visual marking and IOR strategies, such that those who show the most consistent IOR effect are the ones who use visual marking the least. To further explore the individual differences in search strategy posed by the IOR-visual marking dichotomy, the results of Exp 1b and Exp 2 were compared according to high and low visual marking groups defined in Exp 1b. Consistent differences between the high and low marking groups would support the distinction between search strategy preference as a marker of individual search behavior.

First, the visual marking performance of the low and high visual marking groups was examined separately at the group level in the basic visual marking trials of Exp 1b (see Fig 9). Visual marking was present in the high marking group but not the low marking group. This contrasts with the IOR results, in which a significant IOR effect was present in both low and high IOR groups created by a median IOR split [$F(1,14) = 114.3$, $p < .001$ and $F(1,14) = 191.4$, $p < .001$ in the low and high IOR groups, respectively]. The striking thing about the lack of visual marking by the low markers in Fig 9 was that the absence of the effect was being driven more by their ability to search efficiently for the target in the invalid old items condition (when the old items shifted to random new locations as the new items were added) than by their lack of efficient search in the valid items condition. One possible explanation for this result is that the low markers were using IOR to inhibit old item locations even after the old items shifted to random new locations. IOR applied to old locations would have biased search towards new locations, increasing overall search efficiency.

The differences between the high and low marking groups appeared to remain consistent in the results of Exp 2. The high marking group from Exp 1b continued to show strong visual marking in the visual marking control trials of Exp 2, whereas the marking effect did not reach significance in the low marking group (see Fig 13). The appearance of more efficient search by the low markers in the invalid search conditions was maintained in both the IOR-visual marking combination trials of Exp 2 (Fig 14) and the IOR response trials of Exp 2 (Fig 15). In both conditions, search by the low markers tended to be more efficient when the target appeared in an invalid old items condition on the invalid side. The consistent pattern of differences between the search behavior of the high and low marking groups supports the suggestion from Exp 1 that these groups exhibit fundamentally different search behavior. One possible explanation for the difference is that the low markers were using inhibition of return to complete the visual marking task. For the low markers, IOR could have been operating at the individual item locations, especially considering the small number of preview items used in this study. If the individual item locations were being inhibited by IOR, even when invalid, then the inhibition could have lasted beyond the preview period, lingering as the final display was onset, and leading to an advantage in search in the uninhibited areas. This could explain why the low markers (i.e., the more consistent inhibitors), showed more efficient search consistently in the invalid old items conditions of Exp 1b, the IOR-VM comparison trials of Exp 2, and the IOR response trials of Exp 2.

Regarding the study of individual differences in IOR and visual marking, the current results corroborate only one other test of the reliability in an IOR task (Berger, 2006), and are the first known results showing the unreliability of the visual marking effect. The consideration of individual differences in theory construction was considered in an article by B.J. Underwood (1975), who argued that any theory regarding behavior at the group level should include statements about the individual differences component of the behavior. The call for the use of individual differences in psychological studies was renewed by a group of investigators including Kosslyn, Hugdahl, and others (Kosslyn et al., 2002), who argued that neither group nor individual research alone is sufficient, and that the two should be combined. Despite these calls for a greater awareness of individual differences, the application of the study of individual differences is relatively new to both the IOR and visual marking paradigms. The moderate reliability of IOR and the unreliability of visual marking found in the current study should serve as respective caution and warning to investigators interested in using the IOR or visual marking tasks as individual indicators of inhibition or attentional processing. The variability of the visual marking effect could also serve to diminish the overall effect, and could affect the results of any visual marking study. Finally, the most unexpected finding of the current study, that low markers were the most consistent users of IOR, was only possible through the study of individual differences. Perhaps in sum, the current individual differences results could be used as motivation to be more aware of individual behavior when classifying general cognitive behaviors.

One of the central questions in the visual marking literature is whether the preview benefit in visual marking occurs because of processes arising during the preview period (Watson & Humphreys, 1997), or if the benefit is driven more by the onset of the new items in the final display (Donk & Theeuwes, 2001; 2003). An argument could probably be made that the current results support the general view that pre-target processes play a role in the visual marking effect. There were no manipulations of new items in any experiment reported. Thus, all reported effects, either of the presence or diminishment of IOR or visual marking, were due to pre-target manipulations of which participants were always instructed to ignore.

A fair proportion of the visual marking literature has been concerned with research conducted to differentiate visual marking from IOR, including Watson and Humprheys' original research (1997, Exps 4-6). Research with a probe dot in visual marking has supported inhibitory processes in general, but also differentiated visual marking and IOR (Humprheys et al., 2004; Olivers & Humphreys, 2002; Watson & Humprheys, 2000). IOR and visual marking have also been differentiated according to the type of search required in the pre-target period (Olivers et al., 2002), and by comparison of temporal properties (Kunar et al., 2003; Pratt & McCauliffe, 2002). The current research could be added to the list. Individual differences results from Exp 1 suggested a division not only between effects, but in how people differed in their use of the two effects. The group of people who least used visual marking exhibited a reliable IOR effect, while the group most likely to use visual marking did not exhibit reliable IOR. The expression of both effects when the paradigms were combined in Exp 2 can also be taken as evidence supporting the notion that IOR and visual marking are different effects.

If the results of the current research agree that IOR and visual marking are different, the suggestion that some of the visual marking effect could be accounted for by IOR is new among the visual marking literature. This suggestion followed from the examination of search behavior in Exps 1b and 2 according to low or high visual marking ability, which showed that the low markers consistently searched more efficiently in the invalid old items conditions. This could have been because the low markers, shown in Exp 1 to be the more consistent IOR users, were using IOR to inhibit individual old item locations even after the old items were moved in the final display. The co-existence of IOR and visual marking processes would explain the relatively few findings of a visual marking effect occurring during trials in which preview display items disappeared, mimicking the inter-trial interval of IOR tasks (Land et al., 2006; Pratt & McAullife, 2002).

The suggestion that IOR could operate in conjunction with visual marking in visual marking tasks is reminiscent of a study by Jiang and Wang (2004) showing that visual short term memory (VSTM, Phillips, 1974) processes could account for some, but not all of the preview benefit in visual marking. Jiang and Wang examined performance in tasks designed to measure VSTM in comparison with tasks known to produce or eliminate visual marking. They showed that VSTM could account for some, but not all of the preview benefit observed in their visual marking study. They used their results to suggest that marking is composed of at least two types of memory, VSTM and what they called a memory for temporal asynchrony, defined as a large capacity but rapidly decaying memory for groups of items segregated only by their distinct temporal onsets. They could not rule out that a third type of memory, which they called memory for inhibited old items, might also be involved in visual marking. The similarities between VSTM and IOR as both are applied to visual search in general and visual marking in particular included a limited capacity of 4 to 6 items and a duration ranging from a few hundred milliseconds up to at least 3 seconds (Jiang & Wang, 2004; Klein & MacInnes, 1998; Phillips, 1974; Samuel & Kat, 2003; Snyder & Kingstone, 2001). These similarities lead to questions regarding whether and how VSTM and IOR contribute differently to visual search behavior in general, and visual marking in particular. The application of the study of individual differences could be a useful tool in examining the relationship and differential contributions of VSTM and IOR to visual marking.

One final observation can be made regarding the contribution of the current research to the visual marking literature. The current demonstration of visual marking in a divided visual field has never been shown in the visual marking literature. Being able to assess visual marking behavior in a divided visual field brings to mind research suggesting a division between how the different hemispheres process visual information. Ivry & Robertson (1998) proposed the double filtering of frequency theory, essentially accounting for results of research showing lateralization effects in visual information processing. Their theory was based in part on research showing that the different hemispheres show an asymmetry in how they handle spatial frequency information. The left and right hemispheres have been shown to be biased toward high and low frequency information, respectively (Sergent, 1982), and differences in the global interference effect (Navon, 1977) have been found between hemispheres (Sergent, 1982). Given that IOR is thought to operate at a more local level, requiring serial attentional deployments to develop, whereas visual marking seems to operate on groups of items in a more parallel fashion (Olivers et al., 2002), it is tempting to speculate that IOR and visual marking are complementary local and global components of a common visual search mechanism. Such a complementary relationship could be rooted in hemispheric biases in processing local vs. global information. Questions along this line of thinking could be addressed by coupling the current research with eye tracking to ensure no eye movements during the preview period. Different patterns of interference between IOR and visual marking according to the actual side of target appearance would suggest the involvement of a hemispheric component in the IOR-visual marking relationship.

One drawback of the present study lies in the relative newness of the techniques used. The current results can probably be interpreted in ways other than the explanations given. At the least, replications would be expected to verify the interference between the effects observed in Exp 2, the reliability differences seen in Exp 1, and the suggestion that people differ in their inclination to exhibit IOR over visual marking in search behavior. Perhaps the first obvious extension to this study would be to compare low and high markers with increasing numbers of both old and new set sizes. If IOR was operating in the low markers because of the small set sizes used in the current study, the benefit in search efficiency showed by the low markers in the invalid conditions of the current study should disappear with increasing overall set sizes, as the limited capacity IOR system becomes overwhelmed. It would be interesting to know if the reliability differences found in the current study disappeared with increasing set sizes. That is, if it was found that the use of visual marking increased as overall set sizes increased (perhaps out of necessity to process the task), would visual marking then become reliable, or would some continue to show stronger visual marking overall, while others continued to use IOR or other strategies?

In summary, the research reported in this paper was undertaken to compare the IOR and visual marking effects, since both are thought to aid in visual search, both are believed to use inhibition of some sort, and both operate on similar time courses. The common view among visual marking researchers is that the inhibition processes in visual marking are different that those in IOR (Olivers et al., 2002; Watson & Humphreys, 1997). Others have suggested that marking functions like IOR, and that the notion that visual marking is distinct from IOR may be too restrictive (Klein, 2000). The current experiments were designed to address questions regarding the relationship and interaction of IOR and visual marking by examining different individual difference patterns between the effects and by comparing the effects in a task combining the visual marking and IOR paradigms. The current results have added to the growing evidence that the IOR and visual marking processes are indeed separate, but have also opened the door to the possibility that the effects are complementary or related in some other way, and that individuals might differ in their likelihood of exhibiting one effect over the other in visual search.

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