The effects of implicit attentional learning and habituation on inhibition of return

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In two experiments, the effects of implicit attentional learning and habituation on inhibition of return (IOR) were assessed. Experiment 1 consisted of an informative variant of the spatial cuing paradigm (Posner, 1980), with the target appearing most often at the location next to the cue. Short-term as well as long-term learning of the regularities could be observed. This learning took place even though the participants were not able to verbalize the learned information, suggesting that the learning was implicit. By spatially separating the effects of implicit learning and IOR, we demonstrated that the magnitude of IOR slightly decreased because of long-term implicit orienting. In Experiment 2, a noninformative variant of the spatial cuing paradigm, IOR was still found to decrease over the course of the experiment. This suggests that habituation due to the mere repeated initiation of IOR also affects the magnitude of the IOR. This theory is supported by the finding that IOR recovered after short breaks in Experiment 2. However, habituation presumably only played a secondary role in Experiment 1. In sum, IOR was abolished by neither implicit attentional learning nor habituation. Here, the finding that IOR is not easily replaced by implicitly learned orienting clearly indicates that IOR is a powerful, low-level mechanism. We discuss implications of these results for the debate on the function of IOR.

Inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985) is a delay in response time that occurs when a cue and a target follow in rapid succession at the same location. It was first reported by Posner and Cohen (1984). In their seminal experiments, participants had to fixate a point between two horizontally aligned peripheral boxes. At the beginning of each trial, an uninformative cue was presented within one of the boxes, and then a second cue drew attention back to the center. This second cue was followed by the target at the cued or the uncued peripheral location. The critical manipulation concerned the stimulus onset asynchrony (SOA) between cue and target: At short SOAs (up to \sim 250 msec), a valid cue led to faster target detection (i.e., facilitation), whereas at longer SOAs (above \sim 250 msec), the target was reported faster when it occurred at the uncued location. This delayed response at long SOAs was labeled IOR (Posner et al., 1985). Since then, IOR has been replicated and further specified in numerous studies (see Klein, 2000, for a review). For instance, IOR was found to be supramodal (Spence, Lloyd, McGlone, Nicholls, & Driver, 2000), to occur in target detection and discrimination tasks (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997), and to be both space- and object-based (McAuliffe, Pratt, & O'Donnell, 2001; S. P. Tipper, Jordan, & Weaver, 1999; S. P. Tipper, Weaver, Jerreat, & Burak, 1994).

IOR has been interpreted in terms of both attentional and oculomotor theories. Whereas theories on the generation of IOR have focused on motor aspects, the effects of IOR have been found to be both motor and attentional. More specifically, IOR is suspected to be a by-product of saccade programming activated by the peripheral cue and mediated by oculomotor centers responsible for the programming of eye movements (N. G. Müller & Kleinschmidt, 2007; Rafal, Calabresi, Brennan, & Sciolto, 1989; but see Ro, Farnè, & Chang, 2003; Sapir, Soroker, Berger, & Henik, 1999; Taylor & Klein, 2000). Although the initiation of IOR is embedded in motor areas, the consequences of the inhibition have been found to be mostly attentional when IOR is stimulus-induced (Hunt & Kingstone, 2003). Motor components may add to this effect, but only to a restricted extent. IOR thus seems to inhibit the deployment of attention to a location that was previously cued and to which a saccade was programmed. The "lack" of attention at that location results in slowed and impaired processing of information displayed there (Handy, Jha, & Mangun, 1999; Lupiáñez et al., 1997; Reuter-Lorenz, Jha, & Rosenguist, 1996).

The purpose of this inhibitory process is generally seen as improving visual search behavior by encouraging attentional orienting to novel locations (Posner & Cohen, 1984;

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Sapir et al., 1999). More specifically, it has been proposed that IOR reflects a marking mechanism that prevents repeated inspections of already examined locations (Klein, 1988, 2000; Klein & MacInnes, 1999; Wright & Richard, 1998). It thus might help in keeping track of inspected locations when searching through a large number of items.

In relation to this assumed function of IOR, Wright and Richard (1998, 2000) proposed that the activation of the processes underlying IOR is a possible but not mandatory reaction to peripheral stimulation. In their view, IOR only occurs if there is a chance that it may make target search more efficient. According to the authors, this is the case when the location of the target is uncertain (Wright & Richard, 1998). They presume, however, that the processes mediating IOR are not initiated if the perceiver can be fairly sure of the upcoming target location—that is, if the cue is informative. According to Wright and Richard's studies, activation of IOR does not take place in this situation, since it would entail the use of processing resources that would be of no additive value in visual search. This view implies that the activation of IOR can be adapted to present behavioral and general efficiency requirements and is thus—at least to a limited extent—subject to topdown control.

When specifying the purpose of IOR in that way, Wright and Richard (1998) referred to another characteristic of IOR that is still under debate: It is not yet clear how to describe IOR in terms of its automaticity or intentionality (Posner & Snyder, 1975; Schneider & Shiffrin, 1977). Is IOR a bottom-up, stereotypic process initiated by any corresponding stimulus, or is it ruled, or at least modulated, by a person's intentions? Several studies have tried to answer this question by analyzing the relation of IOR to endogenous orienting (Berlucchi, Chelazzi, & Tassinari, 2000; Cheal & Lyon, 1991; Danziger & Kingstone, 1999; Lambert, Spencer, & Mohindra, 1987; H. J. Müller & Findlay, 1988; H. J. Müller & Rabbitt, 1989; Wright & Richard, 2000). By comparing both processes within a single experimental setting, an attempt was made to test whether IOR could be influenced or modulated by the other process, which is generally regarded as under intentional control. The first of the studies concluded that IOR can be suppressed by intentional orienting (Cheal & Lyon, 1991; Lambert et al., 1987; H. J. Müller & Findlay, 1988; H. J. Müller & Rabbitt, 1989). Wright and Richard (2000), however, offered a different explanation: that IOR is not suppressed, but rather is not initiated at all, given the high certainty of the target location. This interpretation is based on their idea that IOR is a partly intentional process that is initiated according to necessity and task demands. Both of these conclusions have been challenged, however, by the studies of Danziger and Kingstone (1999), Berlucchi et al. (2000), and Rafal, Davies, and Lauder (2006). In these studies, IOR and volitional orienting were spatially separated by instructing the participants to orient their attention to a location that was distinct from the cued location. In that way, the authors could demonstrate that IOR can be masked but not suppressed by volitional orienting. These results indicate that IOR is a "powerful" mechanism, meaning that it is stereotypic and hardly influenced

by volitional control (see Berlucchi et al., 2000), a result backed in studies by Berger and Henik (2000), Lupiáñez et al. (2004), Taylor (2005), C. Tipper and Kingstone (2005), and Gabay and Henik (2008).

However, in the recent past, a number of studies have been published that allow for a cognitive component of IOR, with "cognitive" meaning that IOR can to some extent be memory-based or that it operates at a cognitive level (e.g., Jefferies, Wright, & Di Lollo, 2005). The studies examining memory's role in IOR have proposed that IOR can at least partly be mediated by long-term memory (Kessler & Tipper, 2004; S. P. Tipper, Grison, & Kessler, 2003; Wilson, Castel, & Pratt, 2006), by short-term memory (Dodd & Pratt, 2007; Wilson et al., 2006), and by spatial working memory (Pratt & Hommel, 2003). Examining the degree to which IOR is mediated by higher cortical centers, some researchers have found proof, for example, that higher level object identity can be inhibited (Grison, Paul, Kessler, & Tipper, 2005) or that IOR interferes with letter processing (Bowles, Ferber, & Pratt, 2005). However, it should be added that the majority of those studies used relatively complex setups and stimuli to examine the cognitive components of IOR, and thus may have enforced higher level processing that was quite different from the processing observed in a standard IOR experiment (but see Wilson et al., 2006).

The question of how far IOR can be characterized as either reflexive or cognitive/intentional has thus elicited vivid discussion during the last few years, and the outcome has been anything but definitive. The present study aims to further investigate this issue. More specifically, we explored whether the "prototypic" IOR in a standard static display with manual responses is a powerful mechanism by analyzing the relation of IOR and another topdown orienting mechanism—namely, implicitly learned orienting. This mechanism has recently been identified in a number of different paradigms (see Kristjánsson, 2006, for a recent review), among them the spatial cuing paradigm (Posner, 1980). In a number of studies using this paradigm with informative cues, Lambert and colleagues (Lambert, Naikar, McLachlan, & Aitken, 1999; Lambert & Sumich, 1996), Peterson (2000), and Decaix, Siéroff, and Bartolomeo (2002) demonstrated that their participants implicitly learned probabilistic regularities within the stimulus material. As a result of this learning, the participants allocated their attention more efficientlythat is, more quickly and in a more focused way—to the locations predicted by the cue. At the same time, the participants were not able to consciously recall (i.e., verbalize) any of the regularities they used, which implies that they had learned those regularities in an implicit manner (Cleeremans, 2003; Reber, 1989). Since implicit learning originates from experience and develops according to the intentions of the participant, it can be regarded as a topdown-mediated orienting mechanism. By investigating the relation between this mechanism and IOR, the present study is intended to contribute to the characterization of IOR in terms of its automaticity or intentionality.

To our knowledge, the relation between IOR and implicit learning has only been addressed by Decaix et al.

(2002), who conducted two experiments using the spatial cuing paradigm with peripheral cues. In both experiments, participants were first presented with 24 trials in which the cue was not predictive of the target location. In the immediately following 90 trials, the cue predicted the target location with an accuracy of 80%. Whereas the cue predicted that the target would be in the same location as the cue in Experiment 1, it predicted that the target would be in the opposite location in Experiment 2. Participants were not informed of the cue-target relationship. During the noninformative trials of both experiments, participants showed IOR. During the informative trials, however, performance changed. In Experiment 1, IOR was replaced by a small reaction time (RT) advantage for the cued location, which was likely to contain the target. In Experiment 2, in which the cued location usually did not contain the target, the RT disadvantage for the cued location was even bigger than in the noninformative trials. At the same time, participants who were aware of the cue-target relationship (as assessed verbally by a postexperiment questionnaire) did not perform differently from those who were considered unaware. Decaix et al. concluded that implicit learning of the cue-target relationship added to the impact of IOR in the informative trials and that the sum of both processes yielded the observed results.

Such additivity of RTs is generally interpreted as a sign of the simultaneous but independent activity of two processes (see, e.g., Berlucchi et al., 2000; Collie, Maruff, Yucel, Danckert, & Currie, 2000; Danziger & Kingstone, 1999). In line with this idea, the results of Decaix et al. (2002) might be regarded as proof that implicit attentional learning and IOR are independent processes that can nevertheless be active at the same time and in sum produce the observed behavior. There is yet another possible interpretation of the data, given that the additivity of RTs in the experiment of Decaix et al. was merely deduced from highly aggregated values—that is, mean values that contained the data of all points of time of the experiment collapsed to a single value. Instead of the two processes being activated simultaneously, IOR may have been gradually replaced by increasingly effective—that is, quick and focused—orienting during the course of the experiment. In other words, an increasing reduction in uncertainty may have led to a reduction in IOR, as proposed by Wright and Richard (1998, 2000).2 A decision between the two alternative interpretations is not possible on the basis of Decaix et al.'s data.

To clarify this issue, in the present study another approach was taken to investigate the influence of implicit attentional learning on IOR. In Experiment 1, participants were exposed to an informative spatial cuing paradigm. Peripheral cues induced IOR at the cued location and, at the same time, directed attention to a different location. In so doing, the effects of IOR and implicit attentional learning were spatially separated so that their magnitudes could be assessed independently. Furthermore, instead of collapsing all RTs into a single value, we investigated the development of RTs over the complete course of the experiment. Replacement of IOR by implicitly learned orienting during the course of the experiment would argue

for the interdependence of the two processes, with learned orienting modulating IOR. This relationship would be plausible according to the argumentation of Wright and Richard (2000), who assumed that IOR is only activated if the experimental design is noninformative. In contrast, a constant IOR effect throughout the experiment, uninfluenced by the learning of the regularities (and by the related growing degree of certainty), would indicate a powerful and stereotypic IOR mechanism not easily influenced by top-down processes. With this approach, a possible fading of IOR over the course of the experiment would yet not necessarily have to be interpreted as a consequence of implicit attentional learning; the IOR literature offers another possible explanation for a reduction in IOR during a spatial cuing experiment—namely, "practice effects." This expression refers to a reduction of the IOR effect through repeated initiation of the IOR process. Such effects have been observed by Lambert and Hockey (1991), Weaver, Lupiáñez, and Watson (1998), and Lupiáñez, Weaver, Tipper, and Madrid (2001), who demonstrated a decline of IOR over the course of an uninformative cuing experiment.³ Lupiáñez et al. (2001) argued for habituation as the cause of those practice effects. With the term "habituation," they referred to the classical notion of this process formulated by Thompson and Spencer (1966) and Groves and Thompson (1970). In their understanding, habituation is characterized by a diminished behavioral response after the repeated identical presentation of a stimulus. This concept has some important properties, among them spontaneous recovery—that is, a return of the response to the baseline level after a sufficiently long break.

We used spontaneous recovery as a check to ensure that any changes in IOR magnitude in our study could be attributed to implicit learning and not to habituation. In Experiment 1, we checked for spontaneous recovery of IOR. Short breaks were inserted between blocks of trials in order to detect possible recovery of IOR after these breaks. Furthermore, a second experiment was designed that allowed for an even more rigorous check for possible habituation effects. Experiment 2 utilized an uninformative variant of the spatial cuing paradigm; no rule connected the cue and target locations, so any decline of IOR could not be attributed to a reduction of uncertainty. At the same time, the frequency of valid trials, and thus the frequency with which IOR was initiated, was increased relative to Experiment 1. If repeated initiation of the IOR process led to habituation and this habituation caused the decrease of IOR in Experiment 1, one would expect even stronger habituation and stronger recovery in Experiment 2. If, on the other hand, no alteration in IOR were observed in Experiment 2, indicating that repeated initiation per se does not have any impact on IOR, it might be concluded that repeated initiation likewise did not play any role in Experiment 1. The decline of IOR in Experiment 1 might then be attributed to implicit attentional learning.

EXPERIMENT 1

Experiment 1 was conducted to assess the effects of implicit learning, and thus of a reduction in uncertainty

concerning the target location, on the magnitude of IOR. For this experiment, participants worked in an informative spatial cuing paradigm with peripheral cues. The display contained three peripheral boxes, located at the 12, 4, and 8 o'clock positions. In 70% of the trials, the target was presented one position clockwise from the cued location. In 10% of the trials, the target appeared at the cued location, and in another 10% of the trials, the target appeared in the box one position counterclockwise from the cued location. The remaining 10% of the trials were catch trials, interspersed in order to avoid anticipatory responses. In this spatial arrangement, cued and predicted locations were separated, and a control location that was neither cued nor predicted was provided. This procedure was introduced by Danziger and Kingstone (1999) to "unmask" IOR from co-occurring processes. The rule connecting the cue and target locations was not revealed to the participants. It was assumed, however, that they would implicitly learn the regularity while working on the experiment and would make increasing use of their knowledge when reacting.

The three different spatial cue—target relationships resulting from the experimental arrangement constituted the three (within-subjects) conditions of Experiment 1. The first condition consisted of the trials in which the target appeared at the location predicted by the cue (predicted condition). The cued condition comprised all trials in which cue and target appeared in the same position. It should be noted that in those trials the target appeared not only at a cued but also at an unpredicted location. Trials that were assigned to the uncued condition were neither cued nor predicted.

RTs for the three conditions were recorded, and in a next step, the effects of implicit attentional learning and IOR were quantified by calculating certain RT differences. This procedure was based on the idea that RT differences can be used to quantify single psychological processes (Donders, 1868/1969). In accordance with this logic, IOR was operationalized as the RT difference between the cued condition and the uncued condition. It was assumed that the RTs of both conditions would contain the time span necessary to make a response per se and the effects of im-

plicit attentional learning, insofar as the target locations in both conditions were treated as low-probability locations. The only difference between the two conditions was that the cued location had been indicated by a cue, whereas this was not the case with the uncued location. The RT difference between the two conditions was hence assumed to capture the effects of the cue.

Implicit attentional learning was defined as the RT difference between the predicted condition and the uncued condition. Both measures would contain the time necessary for a reaction per se. In addition, both RTs would also reflect the effects of implicit attentional learning, although in different manners: The RTs of the predicted condition would reflect the benefit, which is due to implicit attentional learning, whereas the RTs of the uncued location would reflect the costs. Both time fragments should add up to a comprehensive measure of implicit attentional learning when RTs of the two conditions were subtracted from each other. Figure 1 illustrates the RT components of the cued, uncued, and predicted conditions used to operationalize IOR and the effects of implicit attentional learning in Experiment 1.

Implicit learning was tested in two logical steps. In the first, we tested whether any learning—that is, any change in performance—took place during the experiment. In the second, we tested whether this learning actually proceeded in an implicit manner. Both of these steps will now be elaborated.

To check whether any learning occurred during the course of the experiment, two complementary approaches were taken. First, the RT difference denoting implicit attentional learning was observed over the course of the experiment. Second, the participants completed a generation task immediately after the experiment. This second task should provide an additional proof that any change in behavior (i.e., learning of the target probabilities) occurred as a consequence of the participant's completion of the experiment. In this task, participants were required to predict the upcoming target location after a peripheral cue had been presented. Then, the relative portion of trials in which a certain location was predicted was computed. By testing whether the proportion a location was predicted

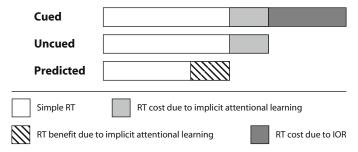


Figure 1. Illustration of the reaction time (RT) components in the cued, uncued, and predicted conditions in Experiment 1 at a given point of time during the experiment. It can be expected that the simple-RT component diminishes over the course of the experiment because of training effects. This effect is assumed to take place to a similar extent in all conditions. At the same time, the effects of implicit learning on RTs are supposed to increase across the experiment.

as where the target would appear corresponded to the location's actual proportion as the target location, this task provided an objective measure of whether participants had implicitly acquired knowledge about where to direct attention in the preceding experiment. Such tasks have been proven to be very sensitive tests of knowledge (Cleeremans, 2003; Cleeremans & Jiménez, 2003; St. John & Shanks, 1997).

In the second step, we checked whether the learning of the cue—target relationship just described had indeed proceeded implicitly. This was done by testing whether the participants were able to verbalize their resulting knowledge. After the experiment, they were asked about the relation between the cue and target locations. The performance of participants who reported the correct relation, and therefore were considered "aware" of the cue—target relationship, was then compared with the performance of those who had failed to do so. If both groups performed the same, learning would not have depended on their explicit knowledge of the cue—target relationship, so the observed behavioral changes could be attributed to implicit learning (see Goschke, 1998).

After we had made sure that learning took place and that it was implicit, the magnitude of IOR could be examined. To investigate the possible effects of implicit attentional learning on the magnitude of IOR, the RT difference between the cued and uncued conditions—that is, IOR—was observed over the course of the experiment. In addition, short breaks were introduced after every second trial block in order to assess recovery effects of IOR that would hallmark habituation as the underlying cause of a decline of IOR during the experiment. Thus, some blocks of trials followed immediately upon another block of trials, and other blocks were preceded by a break. Spontaneous recovery was investigated by comparing IOR in blocks that were or were not preceded by a short break.

We expected to observe effects of implicit learning during the experiment. First, we expected an increasing difference between RTs in the uncued and the predicted condition. Second, in the generation task, the participants should choose the predicted location more often than the two remaining locations, and moreover should predict the two remaining locations equally often. In addition, if IOR is indeed a "powerful" mechanism in relation to the other top-down attentional process, intentional orienting, one would expect IOR to remain stable during the experiment. From this result, we could conclude that IOR is unaffected by the development of implicit attentional learning. If IOR changed over the course of the experiment, however, the behavior across breaks would help to disentangle whether the reduction in IOR was due to learning or habituation. If IOR remained stable in short-term periods (despite breaks)that is, did not show any recovery—we could assume that any change was due to implicit learning and not to habituation. In contrast, recovery effects would be an indicator that habituation was responsible for the decline in IOR.

Method

Participants. Twenty-eight participants (22 female, 6 male) from 19 to 37 years of age (M = 25) participated for course credit. As

was the case for all participants in this study, they reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. The data of 2 participants were removed, in one case because of a high rate of catch-trial responses (29%) and in the other because of a low overall response rate (83%).

Apparatus and Stimuli. Stimulus presentation and the recording of RTs and error rates were controlled by an IBM-compatible PC with an Intel 80586 processor. The stimuli were displayed on a 17-in. monitor (refresh rate 60 Hz). The Experimental Run Time System software package (Beringer, 2000) was used for stimulus presentation and response registration. Participants were placed 60 cm from the screen and responded by pressing a key on a standard computer keyboard.

The standard display consisted of three white boxes and a fixation mark (1.47° of visual angle each) on a black screen. The peripheral boxes were presented at equal distances (8.4° of visual angle) from the fixation mark and equidistant from each other on a black screen. The cue was a flicker (disappearance and reappearance) of one of the boxes. Onset of a white rectangle inside one of the boxes served as the target.

Procedure. In the experiment, three types of trials appeared: test trials, catch trials, and fill trials. The sequence of events in a *test trial* is shown in Figure 2. A test trial began with the presentation of a cue—that is, a vanishing of one of the boxes. The box reappeared after 50 msec. After an interval of 150 msec, the fixation mark vanished for 50 msec in order to guide attention back to fixation. After another 350 msec, the target was presented in one of the peripheral boxes for 200 msec. The SOA between the peripheral cue and the target thus amounted to 600 msec. The interval between the participant's response and the start of a new trial was 1,300 msec.

Catch trials were identical to test trials except for the lack of a target. Keypresses were recorded for 2,000 msec after the fixation mark had reappeared. If participants responded in catch trials, the intertrial interval of 1,300 msec also used in test trials was applied. After either of these two intervals, the next trial started. Finally, in *fill trials*, the standard display was presented for 500 msec without the appearance of any other stimuli. These trials were interspersed in order to prevent routine responding by varying the time span between trials.

Forty trials, comprising 27 test trials, 3 catch trials, and 10 fill trials, constituted one block. The trials were presented in random order within a block, and each peripheral box was cued equally often during a block. Among the 27 test trials, however, the target appeared 21 times in the location clockwise of the cue and 3 times in each of the two remaining boxes. Trials within a block were presented without interruption, and the standard display was visible throughout the blocks.

During the experiment, the blocks of trials were presented as block pairs—that is, 2 blocks were presented with 1 directly after the other, and thus appeared as 1 block to the participant. Each block pair was followed by a 45-sec break. During the break, a counter displayed the remaining time, and a beep announced the start of the next block pair. The whole experiment consisted of 16 block pairs, which were separated by a 30-min break in the middle of the experiment.

Before the experiment, participants received two practice blocks separated by a 45-sec break. Both blocks consisted of 28 practice trials and 10 fill trials presented in randomized order. In the practice trials, the same standard display was presented as in the following test phase. The procedure was identical to that of the test trials in the later experiment, except that no cue was presented. A practice trial began with the flickering of the fixation mark (50 msec). The target was presented 350 msec after offset of the flickering and appeared equally often in each of the boxes. Participants were instructed to respond as quickly and as accurately as possible to the target with a keypress. In addition, they were instructed to keep fixated on the fixation mark and to use the same finger for responding during the whole experiment. Note that no cues were presented during the practice phase, to prevent any influence on the IOR effect in the follow-

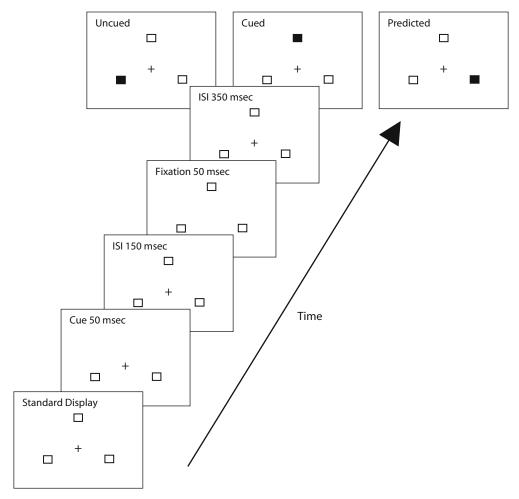


Figure 2. Sequence of events in a test trial. Each experimental trial started with the presentation of the cue (offset of one of the three boxes), which after an interstimulus interval (ISI) of 150 msec was followed by a short offset of the fixation mark in order to draw attention back to the center of the screen. Targets, presented 350 msec later, consisted of the filling of one box. Trials within one block were presented without interruption.

ing test phase. After this practice phase, participants received further instructions preparing them for the appearance of the cue before the flickering of the fixation mark.

Immediately after the experiment, the participants completed a generation task. This task comprised 60 trials, which were presented in the standard display. The chronological sequence of events within a trial was identical to one of the catch trials of the spatial cuing experiment—that is, no target appeared after the cue and the flickering of the fixation mark. The participants were instructed to guess in which of the three possible locations the target would have been presented during the spatial cuing experiment. To do so, they used the arrow keys on the computer keyboard. They were instructed to answer quickly and in an intuitive manner, even if they were not very confident of their answer.

Finally, the participants completed a two-item questionnaire, which probed for awareness of the cue-target relationship. It comprised two items. Item 1 consisted of the following question:

If there was a relationship between cue and target position during the experiment, which of the following relationships would you consider as most likely correct?

All possible cue-target relationships were then provided and visualized by a picture. To avoid sequence effects, the possible answers were presented in randomized order. The participants had to decide on one of the relationships offered. In Item 2, the participants were asked to assess their confidence in the answer just given:

Please indicate your confidence in the judgment just made by circling the appropriate answer:

- —A pure guess.
- -Mainly guesswork.
- —Possibly the correct choice.
- -Probably the correct choice.
- —Very likely the correct choice.
- —Certainly the correct choice.

To determine whether—as intended—the spatial cuing experiment was being performed covertly—that is, without eye movements—5 participants completed the experiment while eye movements were recorded using an infrared eyetracker (Ober2, Permobil, Sweden). Before each session, the eyetracker was calibrated by presenting objects at 1°, 2°, and 8.4° of visual angle, respectively, and asking participants to perform saccades to those objects. Eye movement data recorded during the experiment were then compared with the data recorded during calibration in order to identify eye movements larger than 2° of visual angle. This was done by visual inspection of

the eye movement traces in MATLAB (version 7.4). Eye movements exceeding 2° occurred in 2.96% of the trials (range across participants, 1.25%–4.38%).

In addition, two ANOVAs were conducted to ensure that the results of the eyetracking experiment and the main experiment were comparable. A first ANOVA was calculated on the IOR effect (i.e., the RT difference between the uncued and cued conditions), with experiment (original vs. eyetracking) as a between-subjects variable and epoch (1-8) as a within-subjects variable. Neither the main effect of experiment $[F(1,29) = 0.047, MS_e = 1,854.52, p = .829,$ $\eta^2 = .002$] nor the interaction experiment \times epoch [F(7,203) =0.774, $MS_e = 818.10$, p = .610, $\eta^2 = .03$] was significant. A second ANOVA calculated on the effect of implicit attentional learning (i.e., the RT difference between the uncued and predicted conditions) with the same factors yielded the same results: Neither the main effect of experiment $[F(1,29) = 0.346, MS_e = 1,264.00, p = .561, \eta^2 = .012]$ nor the interaction experiment \times epoch $[F(7,203) = 0.869, MS_e]$ 411.46, p = .532, $\eta^2 = .03$] was significant. The participants thus showed identical results during the main experiment and a control experiment in which we controlled for eye movements. Eye movements hence can be considered irrelevant to the results obtained during the spatial cuing experiment.

Results

In this experiment and the following one, RTs faster than 100 msec or slower than 800 msec, as well as missing responses, were excluded from the analysis. In addition, outliers—that is, RTs more than three standard deviations from a block's mean—were replaced by the mean of the block. After preprocessing of the data, 98.37% of the trials (SD=1.60%) were included in the analysis. Participants responded in 6.37% of all catch trials (SD=7.07%). Errors were not analyzed further.

The mean RT for trial responses within a block was computed separately for each condition. Figure 3 illustrates the mean RTs of each condition as a function of block. These data were submitted to a repeated measures ANOVA with condition (cued, uncued, or predicted) and block (1–32) as within-subjects variables. As was done for all statistical tests in this study, the assumptions for

this statistical procedure were checked graphically and analytically prior to analysis. In the case of violations of the sphericity assumption, Huynh–Feldt's ε was used to adjust the degrees of freedom.

There was a main effect of condition [F(1.39, 35.77) =284.36, $\varepsilon = .70$, $MS_e = 6,663.49$, p < .001, $\eta^2 = .92$], reflecting that from the beginning, RTs in the cued condition were slower than those in the predicted and uncued conditions (see Figure 3). The within-subjects factor block was also significant [$F(11.89, 297.32) = 23.18, \varepsilon = .38$, $MS_e = 7,424.60, p < .001, \eta^2 = .48$], indicating that RTs decreased significantly over the course of the experiment. This decrease presumably reflects a general training effect. Such training effects are a commonly observed phenomenon in learning studies and are supposed to reflect the participant's adaptation of perceptual processing, motor response, and so forth, to the current task. Training took place mostly in the first half of the experiment, whereas the values remained roughly constant in the second half. This is confirmed by a significant interaction in an additional ANOVA with experimental half (1 or 2) and block (1–16) as within-subjects variables [F(8.98, 224.52) = 12.69, $\varepsilon = .60, MS_e = 4,296.12, p < .001, \eta^2 = .34$]. Finally, the condition × block interaction in the original ANOVA proved marginally significant [F(35.92, 822.94) = 1.383, $\varepsilon = .53$, $MS_e = 2,232.33$, p = .076, $\eta^2 = .05$], indicating that RTs in the different conditions developed differently over the course of the experiment.

To further examine this interaction, data were collapsed into eight epochs, and RT differences were computed between the predicted and uncued conditions, on the one hand, and the cued and uncued conditions, on the other.

Figure 4 illustrates an increasing RT benefit for predicted locations relative to uncued locations as a function of epoch. This increase was more pronounced during the first half of the experiment, but it still continued at a lower level in the second half. This development is reflected in the

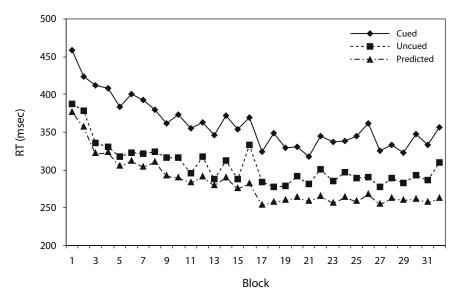


Figure 3. Mean performance in the three conditions of Experiment 1 over the course of the experiment.

RT Difference				35								
Epoch	M	SD	$\widehat{\mathbf{u}}$	30								
1	8.56	20.43	(msec)	25							<./	
2	12.51	15.20	3	25				_	_		•	
3	21.51	20.36	e)	20			•					
4	23.13	27.81	ž				//					
5	23.76	24.69	RT Difference	15		1						
6	29.54	19.78	€	10		*			_	◆ RT d	lifference	
7	25.16	25.35	_	10	4					pred	dicted -	uncued
8	31.94	20.56	₩	5					_	— Pow	er functi	on
GM^*	22.01	23.43		0							er rancer	
*For SD calculation, indi-				U	1	2	3	1	5	6	7	8
vidual data, collapsed to					1	2	3	4	5	6	/	8
8 epoch			Epoch									

Figure 4. (Left) Mean reaction time (RT) differences between the predicted and uncued conditions, and standard deviations (SDs) of the differences, as a function of epoch and aggregated to one grand mean (GM). (Right) Illustration of the RT differences over the course of the experiment. The gray line represents the best-fitting power function through the group mean data.

different slope coefficients of the first and second halves of the experiment: The increase proved significant—that is, the slope coefficient was significantly different from zero—during the first half $[t(1) = 2.826, p = .006; r_{\text{equiv}} = .944]$, whereas it did not differ from zero during the second half $[t(1) = 1.02, p = .314; r_{\text{equiv}} = .71]$. The power function fitted to the data in Figure 4 further illustrates the development of the RT difference over the course of the experiment. The data were entered into a repeated measures ANOVA with epoch (1-8) as a factor. Analysis of the effects of implicit attentional learning revealed an effect of epoch $[F(6.90, 172.59) = 4.37, \varepsilon = .95, MS_e = 380.39, p < .001, <math>\eta^2 = .15]$, indicating a significantly growing RT difference between the predicted and uncued conditions.

Figure 5 illustrates the RT costs of the cued condition relative to the uncued condition as a function of epoch. The RT difference decreased over the experiment, yet most of this decrease took place in the first half of the experiment. This is indicated by a marginally significant slope coefficient during the first half of the experiment $[t(1) = -1.89, p = .061; r_{\text{equiv}} = .89]$, in contrast to a nonsignificant slope coefficient during the second half $[t(1) = 0.12, p = .907; r_{\text{equiv}} = .12]$. During the second half, the RT difference stabilized at a still significant level

[t(25) = 7.60, p < .001; $r_{\text{equiv}} = .48$]. The power function plotted in Figure 5 illustrates this development. A repeated measures ANOVA of the data with the factor epoch (1–8) revealed a significant effect of epoch [F(7,175) = 2.16, $MS_e = 783.95$, p = .042, $\eta^2 = .08$], indicating a significant decrease of the IOR effect over the course of the experiment. An additional repeated measures ANOVA with type of difference (IOR or implicit attentional learning) and epoch (1–8) as within-subjects variables showed that both curves have similar slopes at different points of time during the experiment [F(6,150) = 0.28, $\varepsilon = .86$, $MS_e = 354.64$, p = .947, $\eta^2 = .01$].

To prepare the data for investigating the influence of the 45-sec breaks, the RT differences defined as IOR were collapsed into a mean for even blocks and a mean for odd blocks. Note that the first block of each test half was excluded from this computation, because it was not preceded by a 45-sec break but by an interval of at least 30 min. The mean RT difference between the cued and uncued conditions (corresponding to the IOR effect) was 56.29 (SD = 17.50) in the odd blocks (i.e., those preceded by a break) and 52.91 (SD = 18.93) in the even blocks (i.e., those preceded by another block). A t test for dependent variables showed that the difference in means was

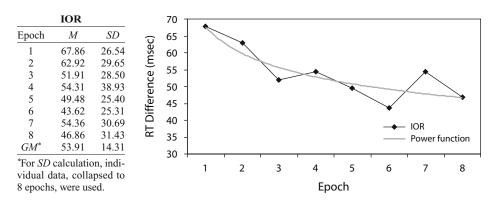


Figure 5. (Left) Mean reaction time (RT) differences between the cued and uncued conditions, with standard deviations (SDs), as a function of epoch and aggregated to one grand mean (GM). (Right) Illustration of the RT differences over the course of the experiment.

not significant [t(25) = 0.812, p = .421; $r_{\rm equiv} = .16$]. However, a significant difference was found for the mean RT difference between the predicted and uncued conditions (i.e., the effects of implicit learning) in the even and odd blocks [t(25) = -2.324, p = .033; $r_{\rm equiv} = .42$]. In the odd blocks, this effect was 17.67 msec (SD = 13.96), whereas it amounted to 24.70 msec (SD = 14.01) in the even blocks.

Generation task. Performance in the generation task was computed as the average number of trials on which participants predicted a certain location. In average, the predicted location was chosen in 47.88% (SD = 18.14%), the cued location in 24.10% (SD = 19.0%), and the uncued location in 27.82% (SD = 10.79%) of the prediction trials. A repeated measures ANOVA of those data (withinsubjects factor location: cued, uncued, or predicted) proved a main effect for location $[F(1.57, 39.31) = 10.55, \varepsilon = .79,$ $MS_{\rm e} = 0.05, p < .001, \eta^2 = .30$]. Post hoc analysis with repeated measures t tests revealed that the location effect was due to a significant difference in the proportion of predicted locations as compared with both cued [t(25)] $-3.40, p = .002; r_{\text{equiv}} = .56$] and uncued [t(25) = -4.48,p < .001; $r_{\text{equiv}} = .66$] locations. Yet, there was no significant difference in predictions of cued and uncued locations $[t(25) = 0.76, p = .457; r_{\text{equiv}} = .15].$

Questionnaire. In the first question of the postexperiment questionnaire, 12 participants chose the correct alternative ("The target appeared most likely one box clockwise from the cued box."). Of the remaining 14 participants, 8 assumed that there was no connection between the cue and the target location, 2 stated that the cue and target most likely appeared in the same location, and 4 assumed that the target appeared most often in the location counterclockwise of the cued location. Confidence in these answers (Question 2 of the questionnaire) was medium (M = 3.21, SD = 0.98), with 1 indicating a pure guess and 6 indicating certainly a correct choice. There was no correlation between the correctness of a choice and the confidence rating ($r_{\rm pb} = .02$). Participants were divided into two subgroups on the basis of their response in the first question of the questionnaire. One group comprised the 12 participants who had given the correct answer—that is, were aware of the rule—and the other group comprised the remaining 14 participants.

Two two-way ANOVAs with one between- and one within-subjects factor were calculated to investigate for an effect of subgroup on performance in implicit attentional learning (i.e., the RT difference between predicted and uncued trials). The between-subjects factor of the first ANOVA was group (aware or unaware), and the within-subjects factor was epoch (1–8). The group × epoch interaction was not significant [$F(7,168) = 0.86, MS_e = 377.30, p = .541, \eta^2 = .03$]. In the second two-way ANOVA, the interaction of the same between factor (group: correct or incorrect) and the within factor block number (even or uneven) was calculated. The group × block number interaction was also not significant [$F(1,24) = 0.02, MS_e = 123.92, p = .903, \eta^2 = .001$].

Finally, we tested whether correct guesses in the generation tasks were solely driven by those participants

aware of the rule. The ANOVA here involved the factors location (cued, uncued, or predicted) and group (aware or unaware). Since there was no location \times group interaction [F(1.48, 32.55) = 0.49, p = .61], it can be concluded that explicit knowledge of the rule did not affect performance in the generation task.

Discussion

Increasingly faster RTs for targets appearing at predicted locations than for targets appearing at uncued locations indicate that implicit attentional learning took place during the spatial cuing experiment. Participants seem to have formed associations between the location of a cue and the location of a following target, so that the appearance of the cue at a certain position apparently activated fast and focused orienting to a certain location relative to the cue. This result resembles the effects of implicit attentional learning identified in other studies (Decaix et al., 2002; Lambert et al., 1999; Lambert & Sumich, 1996; Peterson, 2000) in which faster responses were observed to targets that were predicted by a cue. Performance in the generation task is an additional proof that learning of the cue-target relationship took place during the experiment: Participants correctly predicted that the target would appear at the position clockwise to the cue in most of the trials and at the other two locations with lower but equal frequencies. Furthermore, the nonsignificant interaction between subgroup (as inferred from the answers of the postexperimental questionnaire) and epoch indicates that attentional learning proceeded similarly in both "aware" and "unaware" participants. The learning thus seems not to have depended on explicit knowledge of the underlying rule, and therefore can be termed "implicit."

Parallel to the growing effects of implicit attentional learning, IOR was investigated, and a decline in the mean RT difference between the cued and uncued conditions was found. Since in our experiment cued and predicted locations were spatially separated, this reduction of IOR cannot be attributed to masking by implicit learning, but rather indicates that a reduction in the strength of the IOR process did indeed take place.

This result has two aspects. On the one hand, there was obviously a decline of IOR, which might be interpreted as a partial replacement of IOR by implicit attentional learning. More specifically, this less-pronounced reaction of the IOR mechanism to its triggering stimulus might be explained by the reduction in uncertainty due to learning of the regularities. On the other hand, the observed reduction was relatively small, and IOR was still clearly significant at the end of the experiment. In addition, the fact that the reduction of IOR took place mainly in the first half of the experiment suggests that IOR would not have been much more reduced even if the experiment had been continued for a longer period of time. Hence, IOR was not completely replaced by implicit learning during the experiment, nor would it apparently be replaced in the long run. This result indicates that top-down influences only seem to have a limited impact on IOR.

In sum, it might thus be concluded that there was a partial reduction of IOR in this experiment and that this reduction

could be attributed to implicit attentional learning. This assessment is even supported by a further empirical finding of the present study—namely, the similar slope with which both IOR and implicit learning changed over the course of the experiment. RT changes caused by learning were obviously accompanied by the same RT changes for IOR, suggesting that changes in IOR might be attributable to implicit learning. This argument is not yet compelling enough to definitively refute the idea that habituation could equally well have led to the IOR reduction, as elaborated in the introduction. In order to evaluate this possibility, spontaneous recovery of IOR was assessed, and indeed no difference between the magnitude of IOR in trials after versus before a break could be observed. This lack of a recovery effect might be regarded as evidence that habituation can be ruled out as the cause of the decline of IOR.

However, as mentioned above, analysis of the recovery rate in Experiment 1 was a rather preliminary test for habituation. It has been shown that with sparse stimulation—as in Experiment 1, in which only 10% of trials evoked IOR—recovery is extremely slow (Rose & Rankin, 2001). Hence, although no recovery was observed, habituation might nevertheless have been present in Experiment 1. To test this possibility, we carried out Experiment 2, in which no informative cues were used, and thus, cued trials in which IOR could be observed occurred with higher frequency.

Yet, before beginning the description of Experiment 2, another finding of Experiment 1 shall be mentioned, one that emerged quite unexpectedly but deserves a closer look nevertheless. In contrast to the lack of recovery of IOR, a short-term effect related to implicit learning was observed: Participants were able to detect predicted targets faster in even blocks—that is, in the later trials of a block pairthan in the odd blocks—that is, in trials following the short breaks. In addition, this effect was apparently implicit, as indicated by the nonsignificant interaction between subgroup and block number in the two-way ANOVA. It thus seems that during the experiment, a distinct type of implicit learning of the regularities took place that was characterized by two properties. First, the learning appears to have occurred very rapidly, considering the relatively small number of trials within a block. Second, the finding that RTs in the initial trials of a block pair were always slower than those in later trials suggests that this learning was partly transient, or reduced by a short break. To our knowledge, no effects have been observed in the related attentional learning literature that have featured all of the properties of the short-term learning observed here. There are, however, some parallels to a learning effect observed by Kristjánsson, Mackeben, and Nakayama (2001) and Kristjánsson and Nakayama (2003). In their studies, the authors found a very rapid learning effect that seems to have been based on the immediately preceding trials. In addition, their effect also proved to be implicit. However, whereas the findings of Kristjánsson et al. apply to exogenous orienting, our findings refer to a component of orienting that is active at a later point of time, after stimulation by the cue. In addition, transience was not investigated in the studies of Kristjánsson and colleagues, so their learning effect and our results cannot be compared in this regard. The short-term learning effect observed in our study might therefore represent a new component of implicit attentional learning, or at least a more extensive description of a phenomenon already observed by other researchers. This point shall be taken up again in the General Discussion.

EXPERIMENT 2

Experiment 2 consisted of the uninformative variant of the spatial cuing paradigm. This means that during the test trials, the target appeared with equal probability in any of the three boxes, independently of the location of the cue. Two conditions resulted from this experimental arrangement. In *cued trials*, cue and target appeared in the same location. In *uncued trials*, cue and target appeared at different locations. IOR was defined as the RT difference between the cued condition and the uncued condition.

This variant of the spatial cuing paradigm was used for two reasons. First, it contained no more information on the upcoming target's location, so any possible changes in IOR magnitude could not be attributed to implicit learning or to reduction of the uncertainty in the experimental setting, respectively. Second, this variant had a higher stimulation frequency, since IOR was generated in more trials. If, in Experiment 1, reduction of IOR was due to habituation, one would expect even stronger habituation effects to occur in Experiment 2, in which IOR was initiated with higher frequency. In addition, possible recovery effects of IOR that might not have been discernible in Experiment 1 might become visible with higher stimulation frequency. If habituation does not play any role in relation to IOR, one would expect no decline and no recovery effects in Experiment 2.

Method

Participants. Twenty-four participants (18 female, 6 male) from 20 to 44 years of age (M = 26) participated for course credit.

Apparatus and Procedure. The apparatus was identical to that used in the first experiment. The procedure was also the same, except that in the test trials, the location of the cue did not predict the target location. That is, after the appearance of the cue (which was equally often in any of the three boxes), the target appeared randomly in any of the three peripheral boxes. Participants were not informed of this. After the experiment, participants performed the same generation task and received the same short questionnaire as in Experiment 1.

Also as in Experiment 1, the performance of 5 additional participants was controlled for eye movements, and their results were compared with those of the main experimental group. Eye movements exceeding 2° occurred in 2.02% of the trials (range across participants: 1.25%–3.50%). Again, an ANOVA with the between-subjects factor experiment (original vs. eyetracking) and the within-subjects factor epoch (1–8) was calculated on the IOR effect data (i.e., the RT difference between the cued and uncued conditions). Neither the main effect of experiment $[F(1,27) = 6.82, MS_e = 1,465.18, p = .497, \eta^2 = .03]$ nor the experiment × epoch interaction $[F(7,189) = 0.914, MS_e = 163.29, p < .001, \eta^2 = .03]$ was significant. The RTs and effects of these 5 participants were thus comparable to the results observed for the main group.

Results

RTs faster than 100 msec or slower than 800 msec, as well as missed responses, were excluded from further

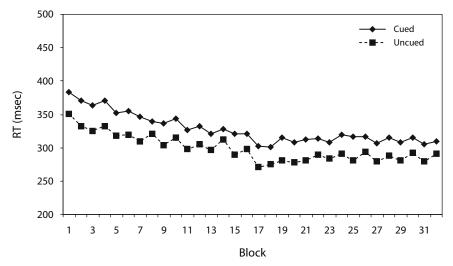


Figure 6. Mean performance in the two conditions of Experiment 2 over the course of the experiment.

analysis. Outliers were replaced by the mean of their particular block. After data preprocessing, 96.63% (SD = 2.80%) of the trials were included in the calculation. Participants responded in 5.82% (SD = 5.04%) of all catch trials. Errors were not analyzed further.

As in Experiment 1, mean RTs were computed for each condition and block. Figure 6 illustrates the course of these RTs over the course of the experiment. Again, these data were entered into a repeated measures ANOVA with condition (cued or uncued) and block (1–32) as within-subjects factors. There was a main effect of condition $[F(1,23) = 93.77, MS_e = 3,324.82, p < .001, \eta^2 = .80]$, corresponding to a significant IOR effect. In addition, the factor block was significant $[F(14.22, 327.02) = 17.78, \varepsilon = .50, MS_e = 2,550.28, p < .001, \eta^2 = .44]$, denoting the effects of training. As in Experiment 1, the decrease took place mostly in the first half of the experiment, whereas the values remained roughly constant in the second experimental half, as confirmed by a significant interaction in an additional ANOVA with experimental

half (1 or 2) and block (1–16) as within-subjects variables [F(9.05, 208.27) = 9.65, $\varepsilon = .60$, $MS_e = 1,691.18$, p < .001, $\eta^2 = .30$].

As in Experiment 1, the data were further collapsed to eight epochs. Figure 7 illustrates IOR as a function of epoch. When the IOR values were entered into a repeated measures ANOVA with epoch (1–8) as a within-subjects factor, a significant effect of epoch could be observed $[F(7,161)=2.25, MS_{\rm e}=168.98, p=.030, \eta^2=.09]$. Analysis of the slope coefficients confirmed that the reduction of IOR was more pronounced in the first half of the experiment: Whereas the regression slope coefficient of the first half differed significantly from zero $[t(1)=2.21, p=.030; r_{\rm equiv}=.91]$, the slope did not do so during the second half $[t(1)=0.982, p=.329; r_{\rm equiv}=.70]$. The power function illustrating this development is plotted in Figure 7.

In addition, the influence of the 45-sec break on IOR was examined. Mean IOR in odd blocks was 26.11 msec (SD = 15.52) and increased to 30.82 (SD = 16.04) in even blocks.

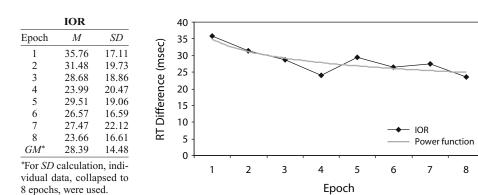


Figure 7. (Left) Mean reaction time (RT) differences between the cued and uncued conditions of Experiment 2, with standard deviations (SDs) of the respective means, as a function of epoch. In addition, the grand mean (GM) of the data aggregated to one single value per person is reported. (Right) Illustration of the RT differences over the course of the experiment.

The difference between the odd and even block approached significance [$t(23) = -1.94, p = .062; r_{\text{equiv}} = .38$].

Comparison: Experiments 1 and 2

To compare IOR in Experiments 1 and 2, the difference in IOR between the experiments was calculated and plotted as a function of epoch in Figure 8. Visual inspection suggests that the decrease in IOR was slightly more pronounced in Experiment 1. However, a repeated measures ANOVA with the factors epoch (1–8) and experiment (1 or 2) revealed no significant interaction [F(6.68, 320.54) = 0.79, MS_e = 515.57, p = .601, η^2 = .02]. Yet, there were main effects of epoch [F(6.68, 320.54) = 3.41, MS_e = 520.20, p = .002, η^2 = .07] and experiment [F(1,48) = 39.11, MS_e = 1,647.91, p < .001, η^2 = .45], with the latter indicating that IOR was more pronounced in Experiment 1 than in Experiment 2.

Generation task. Participants chose the location clockwise of the cued location (corresponding to the predicted location in Experiment 1) in 32.76% of the trials (SD = 13.85%), the cued location in 35.76% (SD = 19.93%), and the other uncued location in 27.85% (SD = 10.16%). When these data were submitted to a repeated measures ANOVA with the factor location (cued, uncued, or predicted), this factor was not significant [F(1.13, 25.9) = 1.18, $\varepsilon = .56$, $MS_e = 0.06$, p = .295, $\eta^2 = .05$]. Hence, no post hoc tests were calculated.

Postexperiment questionnaire. Thirteen participants correctly assumed that there was no regularity between the cue and the target location, 3 thought that the target most often appeared in the same location as the cue (cued location), 4 supposed that the target mainly appeared in the box clockwise of the cued box (corresponding to the predicted location of Experiment 1), and another 4 assumed that the target most often appeared in the box counterclockwise from the cued box (uncued location). Mean confidence in these answers was 2.72 (SD = 0.61), and there was no significant correlation between type of answer and confidence ($r_{\rm pb} = -.13$, p = .531).

As in Experiment 1, participants were divided into two groups, depending on their knowledge of the rule. A two-way ANOVA with one between-subjects factor (group: aware or unaware) and one within-subjects factor (epoch:

1–8) yielded an only marginally significant main effect for group $[F(7,154) = 2.06, MS_e = 171.31, p = .051, \eta^2 = .09]$. The group × epoch interaction was not significant $[F(7,154) = 0.69, MS_e = 171.31, p = .683, \eta^2 = .03]$.

Discussion

IOR diminished during Experiment 2, as indicated by the significant effect of epoch in the repeated measures analysis. The decrease took place predominantly during the first half of the experiment, whereas the IOR effect remained relatively stable during the second half. We thus replicated the results of Weaver et al. (1998), Lambert and Hockey (1991), and Lupiáñez et al. (2001), who demonstrated a significant decrease of IOR over the course of a noninformative spatial cuing experiment. However, these studies differ quite substantially with regard to the magnitude of the decrease in IOR. Our results resemble those of Lupiáñez et al. (2001, Experiment 2) more closely than those of Weaver et al. (1998, Experiment 2), in that IOR in our study was diminished but not extinguished. Strictly speaking, the decline in our experiment is much like the small decrease observed in Pratt and McAuliffe (1999). The extreme decline of IOR during an experiment observed by Weaver et al. thus seems to be an unusual instance of IOR reduction.

Given that with noninformative cuing, implicit learning was not expected to take place in Experiment 2, habituation seems to be the most likely explanation for the observed IOR decline. Furthermore, we observed a trend for spontaneous recovery of IOR after the 45-sec breaks. To our knowledge, such a recovery effect has not been reported before. Although only a trend, this observation further supports the assumption that habituation was present in Experiment 2.

This conclusion immediately leads to the question of whether the IOR reduction in Experiment 1 was driven by habituation as well, rather than by implicit learning. The results of Experiment 2 are rather ambiguous on this matter. On the one hand, on the basis of the results for recovery effects, this possibility is absolutely viable. Possibly, higher stimulation frequency in Experiment 2 led to an "exposure" of habituation, which was already existent to a small degree in Experiment 1 (although it was not significant there; p = .60) and may have caused the decline

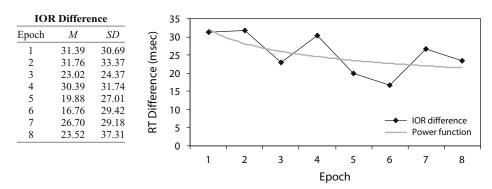


Figure 8. (Left) Mean differences between the IOR values in Experiments 1 and 2, and standard deviations (SDs) of the differences, as a function of epoch. (Right) Illustration of the differences as a function of epoch.

of IOR there. There is also a strong argument against this idea, however: If habituation had been the only factor responsible for the IOR decline in both experiments, this decline should have been more pronounced in Experiment 2 because of its higher frequency of IOR trials. In fact, the decline of IOR in Experiment 2 was just as strong as in Experiment 1.

Why, if habituation was more active in Experiment 2, as indicated by the stronger recovery effects there, was the decline of IOR in Experiment 2 only equally pronounced as in Experiment 1? This obvious contradiction can only be resolved if it is assumed that implicit attentional learning contributed to the IOR reduction in Experiment 1. Hence, although habituation may have been active in Experiment 1 as well, implicit learning must have played a crucial role there and have contributed to the decline observed.

Before we conclude the discussion at this point, it is yet important to mention that still another interpretation of the results of Experiment 2 is conceivable in principle. More specifically, as in Experiment 1, the reduction of IOR in Experiment 2 might have been caused by implicit learning. At first sight, this proposal may seem strange, because uncertainty about the location of the upcoming target could not have been reduced by implicit learning. However, the participants might have learned another regularity: that the relation between the cue and the target was random. This idea is supported by the results of the postexperiment generation task, in which participants expected the target with equal probability at each of the three locations. If participants had indeed implicitly learned that the cue-target relation was random in Experiment 2, they would have had at least two possible ways to adjust their behavior accordingly. First, having "realized" that the cue indicated the correct target position on only a third of trials, they may consequently have directed attention away from the cued location. In this case, IOR should have increased over the course of the experiment—which clearly was not the case. Alternatively, they might have learned to just ignore the cue and instead to distribute attention evenly among the possible target locations. In this case, IOR would decrease over the course of the experiment—just as we observed. This possibility cannot definitely be ruled out by our data. Yet, two arguments can be forwarded against this alternative. First, there was a high similarity between the cue and the target, with both consisting of peripheral luminance changes. This argues for both being part of the attentional set that determined the stimuli to be reacted to (Folk, Remington, & Johnston, 1992; Goschke, 2002; Hommel, 2000). Since the target was to be attended throughout the experiment, it is not plausible to assume that a similar stimulus would be neglected at the same time—in other words, that there would be two different configurations for the same stimulus. It is therefore sensible to presuppose a lasting processing of the cue.

A second argument against implicit learning in Experiment 2 can be deduced from one of the present results—namely, the finding that IOR was generally less pronounced in Experiment 2 than in Experiment 1. This difference is visible from the very first trials (see Figures 3

and 6). Since learning that events are random is harder than, for example, learning the statistical regularity of Experiment 1, and since learning this randomness would certainly require a sufficiently large sample of trials, it can be considered improbable that the immediate effect we observed could be explained by implicit learning. Habituation, on the other hand, should become effective soon after the first trials, and because there were more IOR trials in Experiment 2, the suppressive effect of habituation on IOR should have been more pronounced in this task. This is exactly the result observed in Experiment 2.

On the basis of these arguments, we consider it improbable that implicit learning was the cause of the IOR reduction in Experiment 2. Yet, since those arguments are based on plausibility only, experimental studies will be needed to back these interpretations. This could be achieved with studies that vary stimulation frequency and informativeness of the cue independently of each other.

GENERAL DISCUSSION

We draw several conclusions from the reported experiments. First of all, Experiment 1 provides further evidence that participants implicitly learn regularities in the stimulus material and use the results of this learning to deploy their attention efficiently—that is, quickly and in a focused manner. Furthermore, there is good evidence that both implicit learning and habituation were active in our experiments and caused changes in the magnitude of IOR. The two processes, though, seem to have contributed to the decline of IOR to different degrees in the two experiments. Whereas habituation may have been crucial in the uninformative cuing experiment, the slight decrease in IOR observed in the informative cuing experiment seems to be mostly attributable to the effects of implicit learning and to a reduction in uncertainty. However, it is obvious that neither habituation nor implicit learning were by any means sufficient to abolish IOR. Instead, IOR remained active until the end of our experiments. In sum, the results argue for IOR being a powerful mechanism that is modulated, but not overridden, by implicit learning.

This result supports the conclusion of Decaix et al. (2002) that RT in an informative spatial cuing experiment with long SOAs reflects the effects of both IOR and (longterm) implicit attentional learning. Both of these processes operate simultaneously over the complete course of the experiment. In addition, the present study extends the results of Decaix et al. by demonstrating a small suppression of IOR as a consequence of implicit attentional learning. The influence of implicit attentional learning on IOR is yet only limited here, and in this respect, the relationship of IOR and implicit attentional learning resembles the relationship observed between IOR and the other top-down-influenced process of orienting: intentional orienting (Berlucchi et al., 2000). In both cases, IOR appears to be mostly unaffected by the co-occurring top-down process. It can therefore be concluded that topdown processes generally seem to have little influence on IOR, which consequently indicates that IOR is a relatively low-level phenomenon.

More generally speaking, the present data indicate that the behavioral output is optimized during the course of the experiment. That is, implicit attentional learning results in more efficient orienting, which in turn permits faster perception and reacting at later stages of processing. While this optimization of the behavioral output takes place, at best a partial optimization of the internal processes producing this output seems to occur. There is a very low degree of uncertainty, but nevertheless IOR is initiated. This happens regardless of the fact that implicitly learned orienting, a second orienting mechanism that guides attention away from a cued location and thus serves the same purpose as IOR, is active at the same time. Consequently, the question arises of whether IOR in fact reflects the operation of a flexible marking mechanism helping to keep track of inspected locations by biasing attention away from them (see, e.g., Klein, 1988). Alternative proposals concerning the function of IOR are that it produces facilitated disengagement of attention in order to make it available for new stimuli (De Weerd, 2003) or to avoid interference by salient exogenous stimuli during an intentionally controlled visual search (Rafal et al., 1989). These notions can be reconciled more easily with the results of the present study. Both of the functions might be combined with implicitly learned orienting to jointly produce effective attentional orienting. This consideration might be a starting point for further investigations concerning the functions of IOR.

As elaborated in the introduction, the results and interpretations presented in this study might address a certain instance of IOR—namely, IOR occurring in the standard setup. This instance of IOR may best be described as a rather bottom-up type. However, some recent studies (Bowles et al., 2005; Dodd & Pratt, 2007; Grison et al., 2005; Jefferies et al., 2005; Kessler & Tipper, 2004; Pratt & Hommel, 2003; S. P. Tipper et al., 2003; Wilson et al., 2006) have indicated that with more complicated designs, a top-down component may be involved in the generation of IOR. These two "types" of IOR do not necessarily exclude each other. On the contrary, it is conceivable that both components, the bottom-up component examined in our experiments and the top-down component discovered in other studies, jointly generate behavior in everyday life. Their relative contributions might depend on the complexity of the environment and of the task that is to be accomplished: With simple environments and tasks, the bottom-up component may play a greater role in the generation of IOR, whereas in complex situations the topdown component may have a stronger weight. The present study characterizes bottom-up IOR as a rather stereotypic bias; for a further description of top-down IOR, as well as a further characterization of the interplay of both types of IOR, further experimentation will be required.

Another important finding of this study is the observation of short-term implicit attentional learning in Experiment 1. To the best of our knowledge, this is the first observation of this attentional phenomenon occurring relatively late after stimulation and characterized by rapid development, transience, and implicitness. Because of its rapid buildup, we propose that this learning is determined by the events immediately preceding a certain trial. Furthermore, we suggest that the phenomenon we have observed is an effect of short-term memory (Atkinson & Shiffrin, 1968). The contents of short-term memory can only be retained for a short period of time, and they quickly decay if they are not repeated or further elaborated. This is exactly what seems to happen to parts of the knowledge that is built up during the few preceding trials in an experimental block. The knowledge seems to be partly "lost" during the break, when it is neither renewed nor elaborated. At the same time, parts of the knowledge appear to accumulate as a long-term learning effect that in the present study is termed "attentional implicit learning." A more fine-grained description of the relationship between the observed shortterm learning effect and long-term implicit attentional learning—that is, an answer to the question of whether the short-term learning effect actually is a component of longterm learning, or possibly constitutes a new component of orienting-will require yet further research.

In sum, our results extend those of other studies that have demonstrated the simultaneous activity of multiple processes during orienting (Berlucchi et al., 2000; Kean & Lambert, 2003; H. J. Müller & Findlay, 1988), by demonstrating that IOR and implicit attentional orienting operate simultaneously. A general framework of the common activity of the different attentional processes is not yet well developed and remains a challenge for the future. This framework should be designed with the help of psychological as well as physiological methods. First efforts at investigating the interaction of exogenous and endogenous orienting on a physiological level have been made (e.g., Fecteau, Bell, & Munoz, 2004; Fecteau & Munoz, 2005; Mayer, Seidenberg, Dorflinger, & Rao, 2004; Rosen et al., 1999). These attempts should be extended to the interaction of IOR and implicitly learned orienting, and subsequently to all other processes involved in attentional orienting.

AUTHOR NOTE

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NOTES

- 1. Alternatively, IOR can be saccade-induced (Rafal et al., 1989). In this case, the motor effects of IOR seem to be more pronounced than in stimulus-induced settings (Hunt & Kingstone, 2003).
- 2. Note, however, that Wright and Richard (1998, 2000) made a proposal concerning the effect of *extreme* spatial certainty (more than 90%) on IOR, whereas we also take into account the possibility that IOR can be gradually influenced by an increase of information.
- 3. This finding is not undisputed, however. More specifically, H. J. Müller and von Mühlenen (1996) and Pratt and McAuliffe (1999) failed to find practice effects. Lupiáñez et al. (2001) settled the debate, for the time being, by concluding that a decrease of IOR is possible if certain prerequisites—namely, sufficient saliency of the cues and a fixed SOA—are provided. Although the idea is controversial, it seems at any rate possible that IOR can decline as a result of practice.
 - 4. We calculated r_{equiv} as $\sqrt{F/(F+df)}$ (Rosnow & Rosenthal, 2003).

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