

Using Rescorla's Truly Random Control Condition to Measure Truly Exogenous
Covert Orienting

by

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ABSTRACT

Studies of exogenous covert orienting use peripheral cues (stimuli) that are spatially uninformative about the locations of subsequent targets. When the time course of the cue's influence on performance is explored (by varying the cue target onset asynchrony; CTOA), a biphasic pattern is usually seen with better performance at the cued location when the CTOA is short (typically attributed to attentional capture) and worse performance at the cued location when the CTOA is long (attributed to inhibition of return). However, while spatially uninformative, these cues (even when a nonaging foreperiod is used) entail atemporal contingency with the subsequent target. Consequently, this so-called capture may reflect an unintended consequence of endogenous allocation of temporal attention. Following Lawrence and Klein (2013) we used Rescorla's (1967) truly random control condition to ensure that the spatially uninformative peripheral stimuli were temporally completely uninformative. Even such completely uninformative peripheral stimuli generated the prototypical biphasic pattern.

LIST OF ABBREVIATIONS USED

ACC	anterior cingulate cortex
CS	conditioned stimulus
CTOA	Cue-Target Onset Asynchrony
EM	Eye Movement
FEF	frontal eye field
IFG	inferior frontal gyrus
IOR	Inhibition of Return
IPS	intraparietal sulcus
ISI	Inter-Stimulus Interval
ms	Millisecond
RT	Reaction Time
S-R	Stimulus-Response
SOA	Stimulus Onset Asynchrony
TPJ	temporoparietal junction
UR	unconditioned response
US	unconditioned stimulus

Chapter 1 Introduction

1.1 Networks of attention

Attention is described as preparedness for and selecting from the stimuli in external environment (e.g. objects) or ideas in mind (Raz and Buhle, 2006). It is operationalized as preferential assignment of processing resources to specific stimuli or locations in space that are salient or relevant to the organism. Attention has long been considered to have multiple components or aspects (James, 1890), and different models have been proposed to explain its structure. Posner's tripartite model of attention (Posner and Boies, 1971) is among the earliest models that has been supported by behavioral and neuroimaging data, and findings from studying different clinical populations (Posner and Petersen, 1990; Fernandez-Duque and Posner, 2001). This model proposes three components of attention including alerting, orienting and executive attention (Figure 1a) that are anatomically distinct from processing systems, utilize a system of networks, and carry out different functions (Posner and Petersen, 1990; Fan *et al.*, 2002). The alerting network located mainly in brain stem and right hemisphere is responsible for vigilance and sustained attention. The orienting network located in parietal as well as frontal regions is involved in prioritizing sensory information by directing attention to a specific modality or spatial location. Orienting to external stimuli involves two brain systems: a dorsal system including

1a Networks of Attention	1b Revised Taxonomy		Mode of Allocation	
From: Posner & Petersen (1990) and Fan et al. (2002) the three:	From: Klein & Lawrence (2012)		Exogenous or bottom-up	Endogenous or top-down
Orienting	Domain of Allocation	Space	Capture	Expectancy
Alerting		Time	Alertness	Preparation
Executive Control		Task	Instinct/Habit	Allocation

Figure 1. A framework for attention.

frontal eye field (FEFs) and intraparietal sulcus (IPS) that is identified with rapid strategic attention control, and a ventral system involving inferior frontal gyrus (IFG) and temporoparietal junction (TPJ) was identified with an interrupt signal that occurred after invalid cueing and enabled the switch of attention. The executive attention located in the central frontal regions and anterior cingulate cortex (ACC) is responsible for signal detection and conflict monitoring and resolution. Posner clarifies orienting by distinguishing it from detecting (i.e., processing of a stimulus to the point that it can be reported by the participant verbally or manual key pressing). He argues that some responses (e.g. saccadic eye movements) might be available for orienting even before a stimulus is detected (Posner, 1980).

1.2 Exogenous vs. endogenous orienting

Building upon Posner’s taxonomy of “attention networks”, Klein and Lawrence (2012) have proposed a complimentary model that incorporates different modes of attention (exogenous vs. endogenous) operating within and across different domains (space, time, and task;

Figure 1b). In this model, orienting is divided into exogenous and endogenous modes with respect to the mode of control. Exogenous mode of orienting which is a relatively reflexive mechanism is involved when salient abrupt changes happen in the environment, such as a loud noise. Hence, paradigms aiming to study exogenous orienting are ideally expected to use cues bearing no information that participants can use to predict the targets. Endogenous mode is relatively voluntary and is tuned to learned contingencies and the immediate goals of the organism. To study endogenous orienting, signals preceding the targets predict time or location of targets' appearance. Endogenous orienting can be manipulated by instruction or administering changes in the probability of target stimulus.

Orienting to space which is mostly studied in the context of the visual modality can further be divided into two subdomains: overt orienting where eyes are moved to foveate the relevant stimuli and collect more information about them, and covert orienting which is studied while eyes are fixated to a certain location (i.e., fixation point) away from the target stimuli. Overt and covert subdomains can be considered as the third dimension in this model. Both exogenous and endogenous orienting have been studied in covert and overt subdomains (Posner, 1980). The present study focuses on the exogenous control of covert orienting.

Posner's spatial cueing paradigm is a well-established method used to study exogenous orienting. In this paradigm, a signal is presented

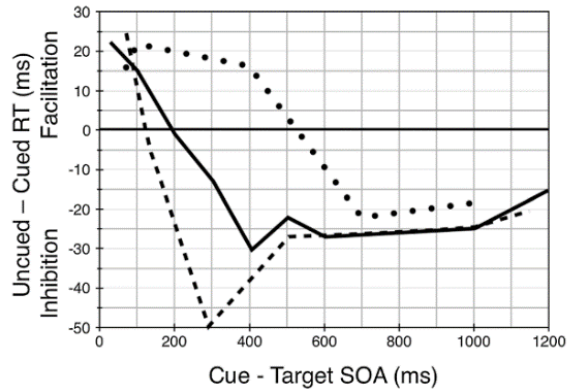


Figure 2. Time course of cuing effects from three different reviews. Time course of cuing effects from three different reviews. Dashed line (Klein, 2000), solid line (Samuel & Kat, 2003) and dotted line (Redden et al., 2016)

briefly in one of two possible locations followed by a target signal to which participants are instructed to respond as quickly and accurately as possible. Given the reflexive nature of the exogenous covert orienting, informativeness of the signals are minimized to prevent the involvement of the endogenous orienting. To that end, the signals are presented in peripheral visual regions in a spatially unpredictable manner: randomly, in half of the trials (i.e., cued trials) signals and targets are presented in the same location, and in the other half (i.e., uncued trials), they appear in opposite locations. The temporal difference between the onset of the signals and targets is called stimulus onset asynchrony (SOA). Typically, participants respond faster to the cued trials than uncued trials in short SOAs, while in longer SOAs the pattern is reversed.

The slower reaction time to validly cued target at longer SOAs is explained as disengagement of attention from the recently attended location and reluctance to return to this location to encourage exploration of the uncued locations is known as Inhibition of Return (IOR) (Klein,

2000). This biphasic pattern observed in the spatial cueing paradigm is demonstrated in Figure 2 from three literature reviews (Klein, 2000; Samuel and Kat, 2003; Redden, Hilchey and Klein, 2016).

Posner's spatial cueing paradigm has been widely used to study exogenous orienting across different tasks (detection vs. discrimination), probabilities of the targets, modalities, signal and target durations, and duration and variability of the SOAs. Most studies have correctly used spatially uninformative cues to investigate the exogenous mode. Spatial uninformative cues is a necessary, but not sufficient strategy to prevent the involvement of endogenous orienting because participants may use the temporal information provided by the cue to predict when the target will be presented.

Woodrow (1914) has shown that in blocks with constant SOA, reaction times are faster than those with variable SOAs, suggesting that the participants can use temporal information of the cues as a reliable source to predict appearance of the targets, while in blocks with variable SOAs the temporal information is not seen as reliable. Another demonstration of how temporal expectancy of the target affects reaction time is the "foreperiod effect". When SOAs inside a block are variable, longer foreperiods (i.e., SOAs) entail faster responses than the shorter foreperiods. This phenomenon is attributed to the conditional probability of target appearance throughout the SOA. As more time passes without the

target appearing, the likelihood of the imminent target increases, and so does the readiness of the participants to respond.

Another account for explaining shorter RTs in longer SOAs is intertrial sequential effect. In studies with variable SOAs, it has been shown that when SOA in a trial is shorter than the preceding trial, RTs are faster (Baumeister and Joubert, 1969; Los, Knol and Boers, 2001), and is attributed to the conditioning effect. To evaluate the intertrial sequential effect, Los and Agter (2005) used three SOAs of 300, 600, and 1,200ms and catch trials in three distribution: uniform, exponential, and peaked. The proportion of SOAs (i.e., 300, 600, 1200ms and catch trials) in uniform, exponential (or “nonaging”) and peaked distributions was 1:1:1:1, 4:2:1:1, and 1:5:1:1, respectively. As a result, the conditional probability of a target appearing at a critical moment was increased in long and central SOAs in uniform and peak distributions, and equal across different SOAs in exponential distribution. By reweighting the sequential effect, they examined the contribution of the sequential effect on the SOA – RT function. They demonstrated that the faster responses in trials with long SOAs can not be explained by sequential influence, concluding that temporal orienting strategies are at play.

One strategy to counteract the effects of temporal expectancy is “nonaging foreperiods” introduced by Nickerson and Burham (1969). In this method, relative frequency of the trials with longer SOAs is reduced proportionately with the length of the SOAs. As a result, the likelihood of

an imminent target and hence, participants' expectancy, remains constant throughout the signal-target period. Gabay and Henik (2008) used this method to resolve the variable temporal expectancy problem which produced the typical biphasic pattern of reaction times in a simple detection task, but failed to do so in discrimination task (Gabay and Henik, 2010). Since this pattern and appearance of IOR is a hallmark of exogenous orienting, this finding and thus, usefulness of this technique in tackling temporal expectancy problem needs more exploration.

All the methods used in the aforementioned studies have used a typical structure in which a fixation period is followed by a cue, followed by a target (or absence of the target in catch trials) followed by a response period (fixation-signal-target-response). This sequence, which characterizes all studies of alerting and orienting entails signal-target temporal contingency that can be employed by the participants to allocate their attentional resources. To explore truly exogenous alerting, Lawrence and Klein (2013) adopted a method from the animal studies literature developed by Rescorla (1967) called "truly random control" procedure. In a typical experiment on Pavlovian conditioning, a conditioned stimulus (CS) such as a tone might be paired with an unconditioned stimulus (US) such as a puff of air to the eye, eliciting an unconditioned response (UR), i.e., eye blinking. A CS will not elicit UR in the absence of the CS, unless it is paired with the US. After repeated pairings of the CS with UC (learning phase), CS will elicit conditional response (CR). A common

control condition to provide a basis for comparison might be observing the rate of UR in the absence of the US and presence of the CS (i.e., studying the number of eye blinks to tones). However, this control condition excludes not only US, but also US – CS pairings. Since an ideal control condition must retain all experimental condition except the US – CS pairing, a better control procedure would be keeping the same number of USs and CSs and eliminating only the US – CS contingency by presenting the CS in random manner and independently from the US. In addition to removing temporal contingency between signals and targets using Rescorla’s truly random control procedure, Lawrence and Klein (2013) also replaced the typical trial structure (i.e., fixation-signal-target-response) with the one in which signals and targets are presented randomly and independently. This way they eliminated the temporal informativeness of the signals, thus enabling them to measure purely exogenous temporal attention.

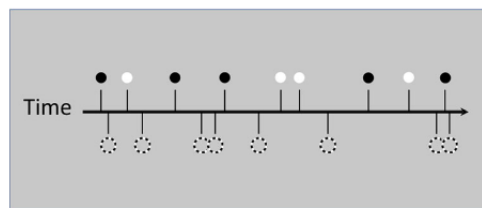


Figure 3. Schematic illustration of the relative timing of targets (full circles) and cues (checkerboard circles)

In the experiment described in Chapter 2, we borrowed this “truly random control” procedure to make the already spatially uninformative cues also temporally uninformative. This structure is shown in Figure 3. We were interested in seeing if by making the signals temporally as well

as spatially informative, we will still observe the typical biphasic pattern in reaction times (early facilitation followed by late inhibition).

Chapter 2 Methodology and results¹

2.1 Participants

Forty participants (18 to 23 years old, 36 right-handed, 34 female), undergraduate students who received extra credit for their participation in the study, contributed the results that are described below. A sample size of 20 participants was initially targeted based on our informal assessment that the phenomena of interest have relatively large effect sizes, with published sample sizes typically ranging from 6 to 24. Preliminary analysis after collection of 20 participants was consistent with those reported below in terms of the point estimates of effects (which in turn were also consistent with the literature), but we found the uncertainty thereon unacceptably large (e.g., 95% confidence intervals spanning up to 80ms) and thus doubled data collection to a total of 40.

2.2 Apparatus and Stimuli

The experiment was implemented on an iMac computer (2.8GHz) with a 27-inch screen. Stimulus presentation and data collection were carried out by a program written in Python by MAL. Participants used a gaming controller to respond. The experiment room was normally lighted. There were two possible target stimuli, either a full black or full white circle with a diameter of 2° presented in a gray background. Targets were centered 10° to the left or right of the center of the screen and presented for 100 milliseconds. There was one type of peripheral cue, consisting of a checkered black and white ring with a diameter of 5°. When presented (for a duration of 50ms), a cue was centered 10° to the left

¹ The material in this chapter reproduces, with permission, the Methods and Results sections from my published paper Habibnezhad, Lawrence and Klein (2019).

or right of the center of the screen. The timing of both targets and cues was randomly generated by independent sampling from a shifted and truncated exponential function with a minimum of 3 s, mean of 4 s, and maximum of 10 s. Cues and targets were randomly assigned to the left or right locations.

2.3 Procedure

After reading and signing the informed consent letter, participants were seated at a distance of approximately 60 cm from the computer monitor. They were also instructed to ignore the cues and to respond to the color of the targets irrespective of their location by pushing the right and left triggers, for the white and black targets, respectively. Participants were instructed keep their gaze focused on the central fixation stimuli and to respond as rapidly and as accurately as possible. Following every response, a number appeared at the center of the screen that indicated participant's reaction time. To provide feedback on their responses, the color of this number was consistent with participant's response (white for the right trigger and black for the left). The experiment began with a short block of practice and was followed by two experimental blocks. Each experimental block was composed of eight sub-blocks, each of which included of 29 targets.

2.4 Design and methods of analysis

Because the experimental procedure entailed random generation of the times of cues and targets, a variety of rules were applied to each target to ensure that we could unambiguously attribute responses to unambiguously cued targets. The application of these rules excluded 46% of the targets and yielded a distribution of SOAs, including some negative ones for which a cue was

presented after a target but prior to the participant's response to that target. We then excluded SOAs below 200ms and above 1200ms, as the distribution of SOAs is approximately uniform from 200ms to 1200ms, but begins to taper off thereafter (i.e., SOAs become increasingly less frequent as they increase beyond about 1200ms), and prior literature indicates we should expect to observe the phenomena of interest in this SOA range. This trimming removed 37% of the remaining cue–target–response triads. Additional exclusions included responses for which more than one trigger was pressed (including presses below response threshold; 3.3%), responses for which RTs were faster than 200ms (0.2% of trials), or slower than 1000ms (0.9% of trials). After all the exclusions described above, a total 7429 responses contributed to the analyses described below. Following Lawrence and Klein (2013), analysis of performance variables (reaction time and accuracy) was achieved by a generalized additive model with subjects contributing a random effect on the intercept. Error data were modeled as binomial and transformed to the percentage and, consistent with the results shown in Fig 4, a significant interaction between the two factors, $F(7, 243) = 2.26, p < .01$, scale for reporting purposes. Only accurate trials were included in the analysis of RTs, and RTs were log-transformed prior to analysis, then transformed back to the millisecond scale for reporting purposes.

2.5 Results

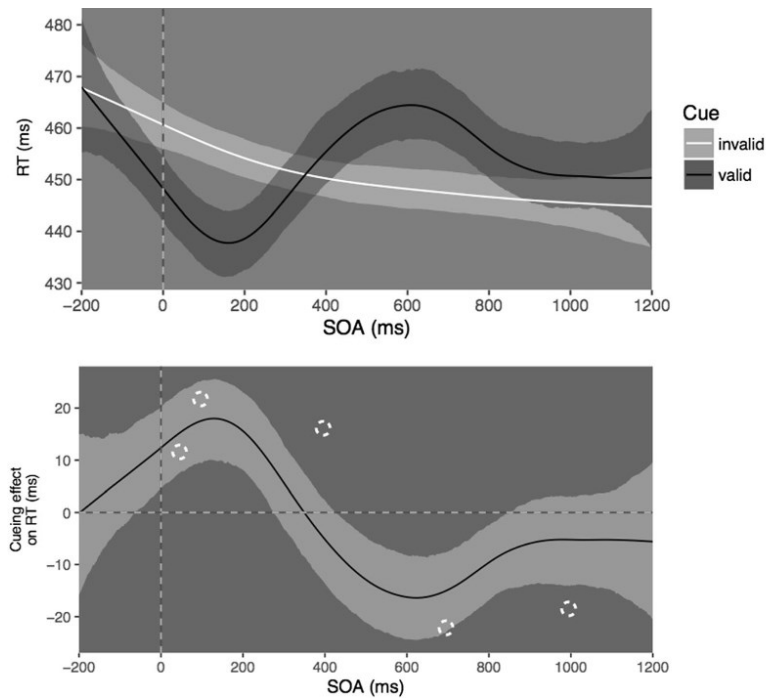


Figure 4. Upper panel: Reaction time as a function of the spatial relation (valid/invalid) and SOA. Lower panel: Cueing effects as a function of SOA. Dashed circles represent findings from the literature as described in the Discussion. Ribbons reflect 95% confidence intervals.

As illustrated in Figure 4, reaction times revealed cue-generated early facilitation followed by a later inhibitory effect. The time of peak facilitation occurred around 127ms (25–198ms) with a magnitude of 18ms (11–26ms), and the time of peak IOR occurred around 620ms (496–751ms) with a magnitude of 18ms (10–25ms). Accuracies did not vary substantially as a function of SOA. The error rate in the Invalid condition was 6.8% (6.3%–7.4%), and in the valid condition, it was 6.0% (5.5%–6.5%). The overall cueing effect on error rate was 0.8% (–0.2%–1.9%), and the 95% CI included zero.

Chapter 3 Discussion

In the current study, we used Rescorla's truly random condition to eliminate any temporal contingencies between the spatially uninformative peripheral cues and the targets. In line with previous findings, our results showed a biphasic pattern of facilitation in short SOAs followed by inhibition in longer SOAs. This biphasic pattern was present although in our study the cues were both spatially and temporally uninformative.

Redden et al (2016) reviewed studies exploring the IOR effect in discrimination tasks and reported reaction times and accuracy rates for each condition. Since they were interested in IOR, they focused on conditions with long SOAs (700ms or longer). But for our purpose, we have considered both short and long SOAs and for which, in the resulting data base, SOAs were represented by at least three independent observations. Cuing effects from these studies are depicted in Fig 4. The biphasic pattern observed in our results is consistent with the results of the review study. However, our results indicate an earlier onset of IOR and less pronounced IOR in the long SOAs. As suggested by Klein (2000), when participants are encouraged to pay attention to the cues, it takes longer to disengage the attention from the initial location, and as a result, IOR is delayed. Since we removed the traditional cue-target structure, the difference in the time course of IOR appearance can be explained by diminished (if not completely eliminated) cue-target contingency (Milliken *et al.*, 2003; Wang *et al.*, 2012). This view explains the delay of the IOR. However, it fails to explain the smaller magnitude of IOR, as well as early facilitation. An alternative explanation would be that removal of cue-target temporal contingency affects the magnitude of IOR, it can be concluded that even the apparent early onset of IOR

is the results of diminished IOR magnitude. The fact that facilitation and IOR magnitude is affected by temporal expectancy is consistent with other findings such as Milliken et al (2003).

The interaction between temporal expectancy and the time course of exogenous orienting has been explored in previous studies. For instance, Milliken et al. (2003) used varying proportions of trials with three SOAs (100, 500, and 900ms) with either a detection or discrimination task and studied how the probability of short, medium, or long SOAs affected the pattern of RTs. In short and long bias condition, 66% of the trials were 100ms and 900ms SOAs respectively, while in unbiased condition, all the SOAs were equiprobable. They found that the time course of exogenous orienting was sensitive to the temporal expectation manipulation, but only in the discrimination task. In detection task, they observed similar time course of facilitation and IOR in long SOAs, regardless of the bias condition. In discrimination task, however, short bias condition entailed stronger facilitation and IOR compared to the other two conditions. In addition, in all conditions, RTs followed the typical biphasic pattern. While Milliken et al. (2003) attribute the change in the trend of overall RTs to temporal expectancy, it is also likely that the alertness is responsible for this trend.

Temporal informativeness of spatially uninformative cues is also shown in a study by Tipper and Kingstone (2005). They had 5 different conditions: baseline group in which all trials had both cues and targets, NoC5 and NoC25 in which 5 or 25 percent of trials did not have cues, and NoT5 and NoT25 in which 5 or 25 percent of the trials did not include targets. Each condition contained a randomly mixed combination of trials with SOAs of 100, 500, or 1000ms. They

observed that while IOR appeared in all conditions, it was attenuated in no target conditions and concluded that increasing the probability of catch trials decreased IOR. While Tipper and Kingstone (2005) attribute the attenuation of the IOR to manipulation of temporal expectancy, alternatively, decreased magnitude of the IOR can be explained by stimulus – response likelihood (Ivanoff and Klein, 2004). On the other hand, as Gabay and Henik (2008) have pointed out, the trend of overall RTs across different conditions is affected by the manipulation of the proportion of catch trials, and the group NoT25 have shown higher overall RTs as well as shallower steep of the RTs. Therefore, it can be speculated that the alertness in this condition has been manipulated and the absence of RT reduction in longer SOAs might be the result of alertness alteration, not necessarily temporal expectancy manipulation.

In an effort to remove temporal expectancy, Gabay and Henik (2008, 2010) employed a method called “nonaging foreperiods” that keeps momentary probability of the target presentation on a specific SOA constant. In most experiments studying exogenous orienting, a limited set of preselected SOAs are used and they are presented with equal probability. As a result, the probability of immediate presentation of the target stimulus increases over time. To overcome this problem, Nickerson & Burnham (1969) suggested nonaging foreperiods method in which the frequency of the longer SOAs decreases. This way, momentary likelihood of the target appearance is kept at 50%. When nonaging foreperiods method was applied to a detection task, the overall foreperiod effect was diminished, whereas typical biphasic pattern of the RTs was present regardless of the distribution of the SOAs. When applied to a discrimination task, however, the biphasic pattern was not observed in nonaging foreperiods

condition. The early facilitation effect was present in all conditions, including nonaging foreperiods condition. This observation suggests that the cue captured attention and then, even though the cue was spatially uninformative, the participants failed to disengage attention from it. Perhaps, as time elapsed during a trial, participants continued to attend the cue while trying to understand how the probabilities were changing. Regardless how one interprets the absence of IOR in this experiment with its non-spatial discrimination task, the dramatic difference in the pattern of results when compared to the same authors' 2008 experiment strongly implies, in agreement with Milliken et al. (2003), that the type of task (detection versus discrimination) matters for the time course of cuing effects in a paradigm with a cue-target trial structure. In this context, we believe that repeating the present application of Rescorla's truly random control condition, which does not have a cue-target trial structure, while changing the task to be performed with the target to simple detection and saccadic localization would be very interesting. As noted by Lawrence and Klein (2013), in any experiment that uses a trial structure (each trial consists of a cue followed by target or catch trial), regardless of the distribution of foreperiods, "the signal always precedes the target, thereby manifesting a temporal contingency." This contingency is not overcome using a nonaging foreperiod or variation in the probability of catch trials. But it is overcome using Rescorla's truly random control condition as we have done here. Therefore, we believe that what we have observed here (Fig 4) is the true time course of exogenous cuing when the peripheral cues are truly uninformative—that is, both spatially and temporally uninformative.

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