Is there stimulus-driven attention without awareness?

By

Michael Budianto

Thesis

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

in

Psychology

August 31, 2022

Nashville, Tennessee

Approved by:

René Marois, Ph.D.

Adriane Seiffert, Ph.D.

TABLE OF CONTENTS

LIST OF TABLES

Tables Page

LIST OF FIGURES

Figures Page

Chapter 1

Stimulus-driven attention

1.1 Introduction

Selective attention is the process by which one can select a subset of internal or external stimuli or events for further processing at the expense of other events (Posner & Boies, 1971). Perceptual awareness, or visual consciousness, refers to the reportable contents of mental life (Kouider & Dehaene, 2007). These two constructs have long been tightly interwoven (James, 1890). Subjectively, we experience that tight bond incessantly as what we pay attention to corresponds to the contents of our awareness. Objectively, the link between the two is reinforced by the robust finding that diverting or overloading attention – using such experimental paradigms as inattentional blindness or the attentional blink – can lead observers to fail to consciously perceive a stimulus that would otherwise have been easy to report (Simons, 2000; Raymond et al., 1992; Asplund, Fougnie, Zughni, Martin, & Marois, 2014). It is also true that a stimulus may not reach awareness even in the presence of full attention if it is presented below the limen for conscious awareness, as in the case of masked stimuli (Merikle & Joordens, 1997), binocular rivalry (e.g., Blake, 1989; Tong, Meng & Blake, 2006), continuous flash suppression (Tsuchiya, Koch, Gilroy & Blake, 2006). Importantly, we know some stimuli that observers are unaware of are still processed to some extent as they leave some trace in the brain, such as in interocular suppression (Fang & He, 2005) and motion-induced blindness (Bonneh, Cooperman & Sagi, 2001) (see Kim & Blake, 2005 for a detailed review).

If the goal is to formalize the functional relationship between attention and awareness, it is useful to specify the form of attention that is being considered. This is because there is both behavioral and neurobiological evidence of at least two forms of attentional deployment; endogenous and exogenous (Corbetta & Shulman, 2002). Endogenous deployment, also known as *goal-directed* or *top-down* deployment, is effortful and voluntary. In contrast, exogenous deployment, also known as *stimulus-driven* or *bottom-up* deployment, is effortless and considered to be automatic (Eriksen, Eriksen, & Hoffman, 1986; Jonides, 1981; Theeuwes, Kramer, Hahn, & Irwin, 1998; Yantis, 2000). This is not to say that these two modes of attentional deployment are fully distinct from one another; indeed they interact (Asplund et al., 2010) and the successful coordination of both is pivotal to nearly every cognitive process (Chun, Golomb, & Turk--Browne, 2011).

In regard to Goal-Directed attention (GDA), its linkage with awareness is apparent when we consciously guide our attention to find a friend in a crowd, for example. On the other hand, the deployment of GDA may not be sufficient to bring up a stimulus to awareness, as when that stimulus is presented under subliminal conditions (Tsuchiya et al., 2006, e.g. flash suppression, see also Meng & Tong, 2004, but cf. Chong & Blake, 2006). The link between stimulus-driven attention (SDA) and awareness might, at face value, to be even stronger. SDA serves to bring up behaviorally-relevant or potentially behaviorally-relevant objects or events to awareness so the observer can evaluate that event and act accordingly (Folk, Remington, & Johnston, 1992). If observer is unaware of the source of SDA, relevant circumstances causing SDA would provide less usable information on how to adjust our behaviors or expectations under those circumstances. As a counter-argument, several groups of researchers (Ivanoff & Klein, 2003; Lin, Murray, & Boynton, 2009; Lin & Murray, 2013; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Sato, Okada, & Toichi, 2007; Schoeberl et al., 2015; Schoeberl & Ansorge, 2018) have proposed that because the deployment of SDA is automatically mediated, such deployment can occur even when observers are unaware of the presence of the stimulus to which attention is deployed. However, evidence presented to support this claim is mitigated, as discussed below.

The purpose of the present study is to critically assess, both on theoretical and experimental grounds, the claim that SDA can be deployed towards an event or stimulus without that stimulus reaching awareness. We first review the current literature claiming to have demonstrated evidence of SDA without awareness. We then present an experiment that attempts to replicate the most compelling paradigm thus far for demonstrating SDA in the absence of awareness (Mulkhuyse, Talsma, & Theeuwes, 2007; Lin & Murray 2013). After finding our data did not comply with the results they obtained, we then re-analyze the data of these two groups. Finally, we will offer an alternative explanation for the results that this paradigm yields. Specifically, we will make the case that the putative demonstrations of implicit SDA in response to suppressed cues actually rely on differential cue awareness that is modulated by the contingent relationship of the cue to the target. After teasing apart the cue awareness data based on cue validity (whether cue's spatial location is congruent with target's spatial location), we will demonstrate that across these conditions, there is no consistent signal sensitivity values indicating that observers are unaware of the cues. We will thus conclude that robust evidence for SDA without awareness has yet to be produced.

1.2 Stimulus-driven attention as automatic cognition

Evidence of automatic cognitive processes is found in a diverse range of behaviors including from simple reflexes (e.g., blinking at a looming object) to highly skilled behaviors (e.g., driving, nonverbal communication, and typing – Charlton & Starkey, 2011; Lakin, 2006;

Logan, 2018), action schema (Tiffany, 1990), and high-level psychological constructs (attitude, stereotyping and prejudice—Galdi, Cadinu, & Tomasetto, 2014). Although theories of automaticity are divided as to the cognitive architecture supporting automatic processes (Bargh, 1992; Logan, 1988; Moors, 2016), the features of automatic processes are largely agreed upon. Specifically, automatic processes are characterized by fast, effortless, and obligatory execution. Such processes can also be executed without attending to the details of the actions being performed (Logan & Crump, 2009; Snyder, Ashitaka, Shimada, Ulrich, & Logan, 2014) and without detailed knowledge about the objects upon which the actions are being performed (Liu, Crump, & Logan, 2010; Logan, 2018). In lay terms, automatic processes can be thought of as those processes that appear to run themselves regardless of the actor's intention.

In one of the first studies explicitly investigating the distinction between goal-directed and stimulus-driven attentional deployment, Jonides (1981) demonstrated that whereas observers could easily suppress GDA deployment and that the efficacy of such attentional processing was capacity-limited and affected by task demands, observers could not easily suppress stimulus-driven orienting regardless of task-set and current working memory load. These findings and the results of additional investigations (e.g., Folk, Remington, & Johnston, 1992; Theeuwes, 1991; Yantis & Jonides, 1984) have led some researchers to conclude that exogenous deployment of spatial attention is an automatic process, provided that observers are attending over a diffuse region of space and that the stimulus capturing attention has the potential to be behaviorally relevant. This automatic attentional deployment (SDA) is usually transient and if the attention-capturing stimulus is behaviorally relevant, attention towards said stimulus is sustained (GDA) (Nakayama &

Mackeben, 1989).

Of course, it is not because a behavior can occur automatically that it does so without awareness; indeed, many of the behaviors mentioned above can occur with awareness. But such dissociation between SDA and awareness has been claimed for the spatial cueing paradigm (Mulkhuyse, Talsma, & Theeuwes, 2007; Lin & Murray 2013). Verifying the claim that SDA can operate outside the bounds of awareness requires two conditions to be met. First, the stimulus used to capture attention must be completely masked from perceptual awareness. Second, any benefits conferred by attention must be attributable only to stimulus-driven processes. Contamination of the results by possible goal-oriented attentional mechanisms, for example, would invalidate a direct appeal to stimulus--driven attention without awareness. As detailed below, in our review of studies claiming to find stimulus--driven attention in the absence of awareness, we have found that one or both of these conditions were not met.

1.3 The spatial-cueing paradigm

As mentioned above, researchers seeking to demonstrate SDA in the absence of awareness have often relied on some variation of the spatial-cueing paradigm (Ivanoff & Klein, 2003; Lin & Murray, 2013, 2015; McCormick, 1997; Sato et al., 2007; Schoeberl & Ansorge, 2018; Schoeberl et al., 2015, but see Lin et al., 2009). The spatial-cueing paradigm refers to any of a class of experimental paradigms in which a spatially circumscribed target is preceded by a stimulus that may or may not validly predict the location of the upcoming target (see Chica, Martin--Arevalo, Botta, & Lupianez, 2014 for a detailed review). In the goal--directed version of the paradigm, the initial stimulus is a centrally presented cue with arbitrarily chosen features that are highly predictive of upcoming target location. For example, a red circle may predict with

75% accuracy that the upcoming target will be presented to the left of center while a blue circle may predict with the same accuracy that the target will be presented to the right of center. In this version of the paradigm, cue--target mapping can be counterbalanced across participants such that there is no unintentional and unexpected bias (e.g., participants somehow orient more easily to the right after presented with blue stimulus). This is to ensure that any reaction -time or accuracy benefits imparted to validly cued targets over invalidly cued targets can be attributed to the effects of purely voluntary shifts in attention. Crucially, truly symbolic cues must predict upcoming target location with above chance in order to produce attentional effects. Results of such experiments demonstrate that endogenously deployed attention typically improves target detection reaction time/accuracy for cues compared to non-cued and invalidly cued trials. Typically, such improvements are observed beginning at cue-target stimulus--onset asynchronies of approximately 300 ms (Remington & Pierce, 1984) and may persist for several seconds (Posner, 1980; Nakayama & Mackeben, 1989).

In contrast, the stimulus-driven version of the spatial cueing paradigm uses non-predictive, peripherally presented stimuli to shift attention to different spatial locations. Such cues may include brief luminance changes (usually giving participants the impression of a flash at the stimulus location) or the sudden onset of new objects at or near possible target locations. These sorts of peripheral cues attract attention to their locations even when observers are explicitly informed that cues do not validly predict upcoming target location. The attentional benefits of peripherally presented cues can be observed at cue-target stimulus-onset asynchronies as short as ~50 ms. However, these effects are short lived, and typically subside within ~300 ms (Nakayama & Mackeben, 1989). In some cases, exogenous cueing even leads to performance decrements at the cued location at cue-target onset asynchronies exceeding 300 ms (Klein & MacInnes, 1999; Posner, Rafal, Choate, & Vaughan, 1985; Wolfe, 1994). This performance decrement is known as inhibition-of-return (IOR), and is theorized to reflect a bias against revisiting previously explored locations (Wolfe, 1994).

1.4 Stimulus-driven attention and awareness

McCormick (1997) published the first paper testing SDA in the absence of cue awareness. McCormick (1997) designed a series of experiments that included a putatively perceptually suppressed cue by using a color Macintosh "dark gray" against the black monitor background in unaware condition. In aware condition, McCormick (1997) presented cues by using Macintosh "white" cues against the same black monitor background. In a target-detection task in which participants were told to make speeded responses to targets, McCormick found a significant effect when targets appeared at the location predicted by the cue, even when that cue was outside the observer's subjective awareness.

While some have taken McCormick's work as compelling evidence (e.g. Wright & Ward, 2008), the logic underlying McCormick's work fundamentally rules out a direct appeal to SDA without awareness because McCormick confounded stimulus-driven and goal-oriented attentional effects. In all of McCormick's experiments, there were cue-target contingencies wherein the cue was predictive of the target location 85% of the time, thus incentivizing participants to adopt a strategy of intentionally looking for a cue. McCormick's work is also problematic because he did not objectively measure cue awareness. Instead, McCormick relied on participants' subjective judgments of cue visibility and adjusted the contrast between the cue and the monitor accordingly. Relying on subjective judgments introduces a criterion effect in which, for any given cue presentation, participants who have adopted a conservative threshold are less likely to report having detected cues than participants who have adopted a more liberal threshold (Swets, 1961, but cf. Cheesman & Merikle, 1996). Consequently, it is impossible to rule out cue awareness as a factor contributing to the reaction time benefits conferred to target detection in McCormick's investigation.

Ivanoff and Klein (2003) addressed many concerns regarding McCormick's (1997) work. Here, the authors instructed participants to complete a go/no-go target detection task wherein the participants were told to make a speeded response to a target when the cue preceding the target was in the 'go' configuration, and to inhibit target response when the preceding cue was in the 'no-go' configuration. Critically, the cue was perceptually suppressed on half of the trials by masking it with two-circle meta contrast. Participants participated in two experimental blocks. In the first block, participants completed only the go/no-go task. In the second block, participants additionally indicated cue awareness at the end of each trial. Thus, the first block constituted a single task, whereas the second block imposed dual-task conditions on the participants. The authors found evidence of IOR in the experimental block in which observers did not additionally indicate cue awareness at the end of each trial. The authors argue that IOR is a purely stimulus-driven effect, and that therefore the presence of IOR indicates the deployment of SDA.

The imposition of the dual-task condition makes it difficult to interpret Ivanoff and Klein's (2003) results. Participants in the dual-task condition had to deploy both goal-oriented and stimulus-driven attentional processes in order to actively look for the cue as well as make a speeded response to the presence of the target. In contrast, participants in the single-task condition only had to deploy stimulus-driven attentional processes to make speeded target responses. The researchers found that the imposition of a second task led to qualitatively different results in the target-detection task. Specifically, the researchers found that evidence of inhibition of return when participants were required to only complete the go/no-go task. In other words, reaction time to target detection was significantly slower at validly cued locations than at invalidly cued locations in the single-task condition. However, this effect disappeared and was replaced with a significant validity effect in the dual-task condition.

Ivanoff and Klein (2003) based their argument for the existence of SDA in the absence of cue--awareness on the significant IOR effect observed in the single--task condition. However, IOR is not necessarily a hallmark of SDA. Not only have researchers demonstrated that IOR need not occur in tandem with the performance enhancing effects of stimulus--driven attention (Fuchs & Ansorge, 2012; Posner, Walker, Friedrich, & Rafal, 1984), recent evidence has further suggested that inhibition of return can be observed at endogenously attended locations provided that no attentional disengagement has occurred (Berlucchi, 2006; Chica, Lupiáñez, & Bartolomeo, 2006; Martin--Arevalo, Kingstone, & Lupianez, 2013). One possible explanation of IOR is reduction of target signal sensitivity caused by stimulation of previously presented cues. The RT inhibition in this case was not accompanied by RT facilitation in valid cue location. IOR then cannot be due to return from cued location if there was not any attentional orienting effect (Berlucchi, 2006; Posner & Cohen, 1984). Consequently, the mere presence of IOR does not constitute strong evidence for the deployment of SDA in the absence of stimulus--awareness.

In yet another study, Schettino and colleagues (2016) investigated the electrophysiological correlates of SDA in the absence of awareness using an ERP component linked to attentional orienting (N1pc; Verleger, vel Grajewska, & Jaśkowski, 2012). In their experiments, participants were either told (experiment 1) or not told (experiment 2) about the existence of uninformative cues, which was in the form of a briefly (20 ms) thickened rectangle placeholders. Experiment 1 served to investigate the level of participants' awareness of briefly presented cues, while experiment 2, conducted with a set of new participants, served to preclude any top-down attentional effects as participants were not told about the cue existence. For the main task, participants were instructed to perform a temporal order judgment (TOJ) task in which they had to respond which of two possible stimuli appeared first. Behaviorally, they found response bias towards the location of cues (compatible cue-target condition), indicated by faster reaction time. Moreover, they found that N1pc (130-180 ms post-target) amplitude was largest when reorienting was needed (incompatible cue-target location), while N1pc-target amplitude in compatible cue-target condition was smaller than both cue-absent and incompatible cue-target conditions as reorienting was not necessary. Central to our discussion, the authors measured cue signal-sensitivity (*d'*) (Tanner & Swets, 1954) and response bias (β) for cue-present and cue-absent trials in experiment 1. They found that cues were not consciously perceived as indicated by $d' \approx 0$ and $\beta \approx 0$. Using Bayesian analysis, experiment 1 and 2 yielded similar results. Thus, they concluded that reaction time benefits obtained in experiment 2 were due to unconsciously perceived (experiment 1) exogenous cues. Although this study was not contaminated by top-down attentional processes like other studies discussed so far, we demonstrate in this study that differential analysis on *d'* might be warranted.

Sato et al. (2007) attempted to demonstrate stimulus-driven attentional effects in the absence of awareness using a paradigm that included two major deviations from traditional SDA spatial cueing paradigms. Specifically, the authors elicited the deployment of stimulus-driven attention via eye-gaze cues that were rendered perceptually invisible. Using this paradigm, the authors found that subliminal gaze shifts can lead to a significant reaction time advantage for gaze shifts that validly indicated upcoming target location compared to shifts that did not validly indicate upcoming target location. As detailed below, although at face value these results seem like compelling evidence in favor of the deployment of SDA in the absence of awareness, the use of eye-gaze cues introduces the possibility that the results were due, at least partially, to processes other than SDA. Ecologically meaningful symbols such as eye-gaze or overlearned stimuli such as directional arrows have often been used as cues in endogenous cueing paradigms (Friesen & Kingstone, 2003a, 2003b; Friesen, Moore, & Kingstone, 2005; Friesen, Ristic, & Kingstone, 2004). Unlike truly symbolic cues, however, centrally presented overlearned symbols can direct spatial attention even when they are not predictive of upcoming cue location (Bayliss & Tipper, 2005; Hommel, Pratt, Colzato, & Godijn, 2001; Marotta, Lupianez, Martella, & Casagrande, 2012), suggesting that, to some extent, attention is deployed involuntarily to the cued location. Further, attention deployed in response to gaze cues displays behavior that is either suggestive of exogenous or endogenous orienting depending on the onset asynchrony between cues and targets. At intermediate onset asynchronies, gaze cues appear to elicit attentional deployment with characteristics of both reflexive and volitional attention (Friesen, Ristic, & Kingstone, 2004). These results demonstrate that attention directed by overlearned symbols cannot be considered to be purely a result of either endogenous or exogenous processes (Awh, Belopolsky, & Theeuwes, 2012) and, therefore, Sato et al.'s (2007) results do not constitute strong evidence for exogenous deployment of SDA absent stimulus awareness.

Although the bulk of research investigating SDA without awareness has used spatial-cueing paradigms in which the cues are putatively rendered invisible via masking, this is by no means the only paradigm that has been employed. A study by Lin, Murray, and Boynton (2009) used looming stimuli to direct attention to specific spatial locations. In this study, the authors claimed that threatening stimuli could elicit SDA to specific spatial locations even when observers were not aware that the stimuli presented a threat. Specifically, the researchers asked participants to detect targets that were preceded by looming stimuli whose paths appeared to either collide with the observers' heads (threat) or to barely miss the observers' heads (non-threat). Even though observers were unable to reliably differentiate between threatening and non-threatening looming objects, targets that appeared at the threatening stimuli's points-of-origin were detected more quickly than targets that appeared at the non-threatening stimuli's points-of-origin.

Like Schettino et al.'s (2016) study, this paradigm does not suffer from possible contamination by goal-directed attentional processes. However, it does not address the crucial question of whether SDA can be deployed in the absence of stimulus awareness. Rather, observers in this study were perfectly aware of the looming stimulus, although they were unable to reliably indicate whether or not the stimulus was threatening. In other words, the authors demonstrate that SDA can be deployed in response to objects whose characteristics are not completely known to the observers. They do not demonstrate that SDA can be deployed in response to objects whose existence is completely hidden from observers.

Chapter 2

Case study and replication

2.1 Case study: Mulckhuyse et al. (2007)

Mulckhuyse et al. (2007) pioneered a paradigm that appears to demonstrate compelling evidence for SDA in the absence of cue awareness. This paradigm has been adopted and adapted by subsequent studies (Lin & Murray, 2013; Lin & Murray, 2015; Schoeberl et al. 2015; Schoeberl & Ansorge, 2018) to explore the consequences of SDA without awareness. Because the paradigms in these follow-up studies are similar in principle to Mulckhuyse's original study, we will focus the methodological critique on the original study, the results that it demonstrated, and their implications. However, we will refer to these other studies whenever appropriate to the discussion.

Mulckhuyse et al. (2007) presented a modified cueing paradigm (Posner, 1980) in which participants were told either to detect a target as quickly as possible or to localize the position of the cue. Mulckhuyse et al. separated the two tasks into different blocks to avoid creating a dual-task condition, dissociating the effects of top-down attentional sets from unaware bottom-up cues. Mulckhuyse et al. and subsequent researchers using a similar design (Lin & Murray, 2013; Lin & Murray, 2015; Schoeberl et al. 2015) found a reaction time advantage for targets that had been validly predicted by putatively unaware cues after a 16.7 ms cue-target onset asynchrony. Mulckhuyse et al. also found a significant effect of inhibition of return after a 1016.7 ms cue-target onset asynchrony (figure 1, under Method section).

If the reaction time results presented in Mulckhuyse et al. (2007) were elicited under conditions of complete perceptual unawareness, this would present compelling evidence of SDA that is not predicated on cue awareness. Mulckhuyse et al. attempted to objectively measure cue awareness by requiring participants to complete two-alternative forced choice task to localize the position of the cue following the completion of the speeded target detection task. Typically, forced-choice methods are thought to be conservative, and have been hailed as the gold standard for establishing unconscious processing. However, recent evidence published by Lin & Murray (2014) suggests that typical alternative forced-choice methods of assessing stimulus awareness may, in fact, underestimate the extent to which participants are aware of stimuli. Specifically, Lin & Murray (2014) demonstrate that chance performance in two-alternative forced choice tasks is due to a combination of (1) participants failing to understand task instructions when all trials are at the threshold of awareness (i.e., when the target stimulus is strongly masked) and (2) priming of the target object increasing the perceptual trace of the target and boosting it above the threshold of awareness.

In addition, Schoeberl and colleagues (2015) also argued that Mulckhuyse et al. (2007)'s study is vulnerable to possible top-down influence due to target-distractors luminance contrast and a singleton feature of cues and targets. They argued that the stark difference between the luminance of targets and of distractors may influence participants to look for targets based on contrast, giving rise to the possibility that attentional capture by unaware cues was due to top-down goals. Schoeberl et al. (2015) addressed said possibilities by coupling target onsets with multiple colored distractors to avoid singleton search and adjusting both targets and distractors' perceived lightness to avoid contrast search. Indeed, they found spatial cueing benefits elicited in validly cued trials.

In yet another study, Schoeberl and Ansorge (2018) removed another possible top-down confound from Schoeberl et al.'s (2015) study – and by extension from Mulckhuyse et al.'s (2007) study as well –; cues serving as an alerting signal. There is evidence that cue onsets may serve as an exogenous temporal alert system (Laidlaw & Kingstone, 2017), and hence participants may use cues in a top-down manner to alert them temporally of incoming targets. In their study, Schoeberl and Ansorge (2018) removed this potential contingency by presenting some of the cues after the target onsets (experiment 1) and intermixed them with cue-absent and no-go trials (experiment 2). Despite the removal of this contingency, the investigators still found reaction time benefits in the validly cued condition and concluded that this represented strong evidence for SDA without awareness. Importantly, Schoeberl and colleagues (Schoeberl et al., 2015; Schoeberl & Ansorge, 2018) assessed participants' awareness of the cues using *d'* as a measure of signal sensitivity (Tanner & Swets, 1954) in a separate task in which participants were asked to indicate the location of the cues. They found that participants were not aware of the cues ($d' \approx 0$).

The concerns above notwithstanding, Mulckhuyse et al. (2007) and Lin & Murray (2013) both argue that reaction time facilitation at validly cued locations in conjunction with chance performance in the two-alternative forced choice cue-localization task indicate the presence of SDA without awareness.

We first tried to replicate Mulckhuyse et al. (2007)'s study as a prelude to our fMRI study, which was aimed to investigate neural correlates for SDA without awareness. However, we were only able to replicate Mulckhuyse et al. (2007) findings in the target-detection task, but not cue-localization tasks. With this in mind, we looked at Mulckhuyse et al. (2007) and Lin & Murray (2013) and reanalyzed their data.

2.2 Mulckhuyse et al. (2007)'s replication

2.2.1 Analysis

In our study, we analyzed participants' cue awareness in cue localization task using *d'*. *D'* is a measure of sensitivity to a given signal (Tanner & Swets, 1954). A *d'* score of 0 reflects chance-level performance, or total lack of perceptual awareness Generally, *d'* is calculated by subtracting a normalized measure of false alarm rate—erroneous detections of a signal when no signal is present— from a normalized measure of hit rate—correct detections of a signal that is actually present. Because this experiment presents a signal on every trial going into the analysis, we arbitrarily chose to consider trials in which participants correctly localized leftmost cues as "hits," and trials in which participants incorrectly said that rightmost cues appeared on the left as "false alarms".

2.2.2 Method

2.2.2.1 Participants

Sixteen participants (11 female; mean age, 25.7 years) participated in the experiment. All participants participated in the target-detection task followed by the cue-awareness task, in that specific order. We did not reverse the task order in order to keep the experimental design identical to that of Mulckhuyse et al. (2007) and because if participants participate in cue localization task first, they would be aware of the cue existence in target-detection task, allowing the possibility for top-down influence even when the cues are not predictive. All participants were recruited using the Vanderbilt SONA recruitment system and were compensated at $12/hour rate or for course credit. All participants reported normal or corrected-to-normal vision. All experiments were performed in accordance with the Vanderbilt University Institutional Review Board.

2.2.2.2 Display

All stimuli were presented on a MacMini computer running MATLAB 2007 (www.mathworks.com) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants were seated at approximately 60 cm from the monitor in a quiet, non-illuminated room. All measures of stimulus size in degrees of visual angle are reported from a 60 cm viewing distance. Participants were explicitly instructed to maintain fixation on the center of the screen throughout the duration of both tasks, and they responded with their dominant hand using a Macintosh keyboard. All stimuli were presented on a light gray background.

2.2.2.3 Procedure and design

The experiment was modeled after Mulckhuyse et al.'s (2007). Participants completed five blocks of a target detection task and four blocks of a cue localization task (see Figure 2.1). 16 participants participated in the target detection-task first and then the cue-awareness task. The cue localization task was visually identical to the target detection task except that during cue localization participants were instructed to ignore the target. The target-detection task was identical to the procedure published in Mulckhuyse et al. (2007). The cue localization task was also identical to Mulckhuyse et al. (2007)'s except for the following slight modification: Whereas Mulckhuyse et al. allowed participants to respond with the location of the cue as soon as the cue was presented and began a new trial as soon as participants keyed-in their responses, we forced participants to wait until the end of each trial to localize the cue. This modification rendered the cue-localization trials to look identical to the target detection trials from the participant's standpoint.

2.2.2.3.1 Target detection task

This task consisted of five blocks of 40 trials, for a total of 200 trials. Each experimental condition: short-cue-target onset asynchrony (CTOA, 16 ms) valid (SV), short-CTOA invalid (SI), long-CTOA (1016 ms) valid (LV), long-CTOA invalid (LI) was repeated eight times per block, for a total of 32 trials per experimental condition. In addition, eight trials per block had no target. These no-target (NT) "catch" trials were included to encourage participants not to respond prior to target presentation. Participants who responded prior to target presentation or during "catch" trials heard a tone indicating an incorrect response. Cues are not predictive of the target location. Half of all target-present trials are validly cued, while the remaining trials are invalidly cued.

Each trial began with 1000 ms fixation on a black cross (0.6º visual angle) at the center of the screen, followed by a 217 ms blank gray screen (the screen was light gray for the duration of both the target detection and cue sensitivity tasks). Following the blank screen, a gray cue disk (2.6º visual angle, center 9.2º away from the center of the screen either to the right or to the left) appeared. After a 16.7 ms cue period, two placeholder disks that were identical to the cue disk appeared. The three disks were arranged in a straight line along the horizontal meridian of the monitor with 9.2º visual angle separating the center of each element. As did Mulckhuyse et al. (2007), we included two CTOAs. The target appeared concurrently with the two placeholder-disks in the short CTOA condition and

1000 ms after the onset of the two placeholder-disks in the long CTOA condition (see figure 2.1). The target was a black dot that appeared in the center of one of the peripheral gray disks. The black dot stayed on the screen for 83ms, and participants were instructed to hit the spacebar as soon as they detected the target. The trial was considered valid if the cue and the target were presented at the same location. There were no targets presented in catch trials. The disks remained on the screen for 200 ms following target offset. There was a 1000 ms inter-trial interval.

2.2.2.3.2 Cue localization task

As with Mulckhuyse et al., the cue localization task consisted of four runs of twenty trials per run. The proportion of valid, invalid, and no-target trials was the same in the cue localization task as in the target detection task. The cue localization task was identical to the target detection task, with the following notable differences. Participants were instructed to ignore the target and attend to the onsets of the cue and placeholder disks. Participants were also told that the location of the black target dot was random and did not provide any information pertinent to completing the localization task. Following the 200 ms inter-trial interval, participants were asked to indicate which of the two peripheral gray disks appeared first on the screen. Participants pressed the ‘z’ key for leftmost disk, and the ‘m’ key for rightmost disk. Participants were required to respond on every trial, and there was no option to say that all disks appeared simultaneously. Each trial ended when a response was given (figure 2.1). No feedback was given except for beep sounds when participants responded during the “catch” (no-target) trials to discourage them from anticipating for responses every trial.

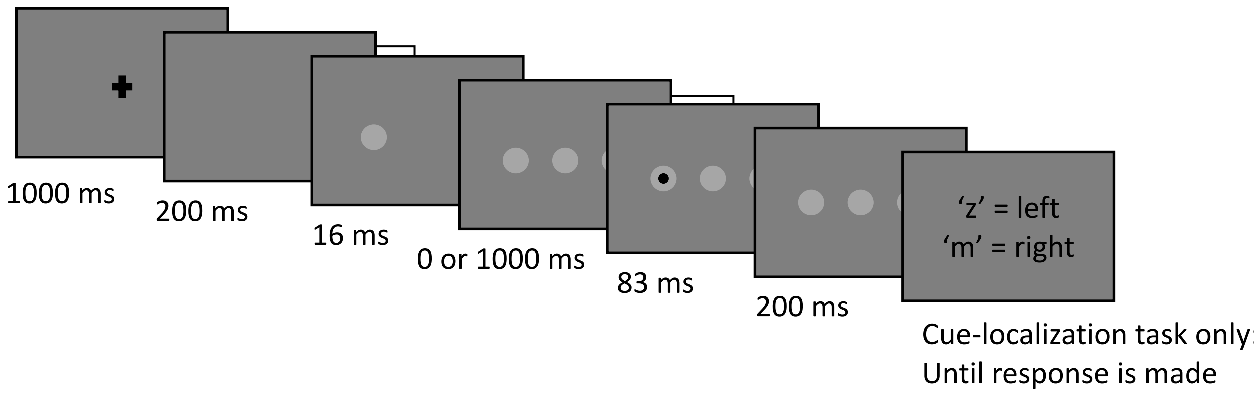


Figure 2.1. Experimental design in both target detection and cue localization task in both Mulckhuyse et al. (2007) and our study. Cues are present in all trials. Cues precedes targets in 80% of all trials. In the remaining trials (20% of all trials), there is no target, "catch" trials. Trial structure for cue sensitivity and target detection tasks. Both tasks are identical until the probe frame. The target detection task omits the probe frame.

2.2.3 Results

2.2.3.1 Target-detection task

2.2.3.1.1 Accuracy

The accuracy was not significantly different across all 4 conditions (SV, SI, LV, and LI). We found no significant effect for CTOA or Validity ($F(1,22) = 0.265$, $p = 0.608$ and $F(1,22) = 0$, $p = 1$ respectively) and no evidence of a significant CTOA x Validity interaction, $F(1,22) = 0.471$, $p = 0.494$. The target detection accuracy is 98.6% across all conditions (SV, M = 98.8%, SD = 3.68%; SI, M = 98.4%, SD = 4.17%; LV, M = 98.7%, SD = 1.98%; LI, M = 99.1%, SD = 1.43%). This demonstrates that participants were able to respond to the correct target location which appeared for 83 ms with high accuracy.\

2.2.3.1.2 Reaction time

Figure 2.2 shows mean reaction time (RT) scores for each condition (SV, SI, LV, LI). Using the same exclusion criteria as Mulckhuyse et al. (2007), reaction time latencies less than 100 ms and greater than 630 ms (1.13% of all trials with targets) were dropped from the analysis. We analyzed the data by running a mixed-factors repeated-measures analysis of variance (ANOVA) with Cue-Target Onset Asynchrony (2 levels; 16 or 1016 ms), and Cue Validity (2 levels; valid or invalid) as fixed effects. We found main effects of CTOA, $F(1,22) = 11.54$, $p = 0.001$, but we found no significant effect on Validity, $F(1,22) = 0.004$, $p = 0.949$ and no CTOA x Validity interaction, $F(1,22) = 0.443$, $p = 0.507$. The data replicates the validity effect found by Mulckhuyse et al. in that participants have shorter RTs for validly cued trials than for invalidly cued trials, $t(22) = -3.34$, $p = 0.03$ at the short CTOA. While the RTs were on average shorter for the invalid than the valid condition at the long CTOA, this effect was not significant $t(22) = 1.01$, $p = 0.32$, unlike in Mulckhuyse et al (2007). Hence, there was no IOR in long CTOA condition.

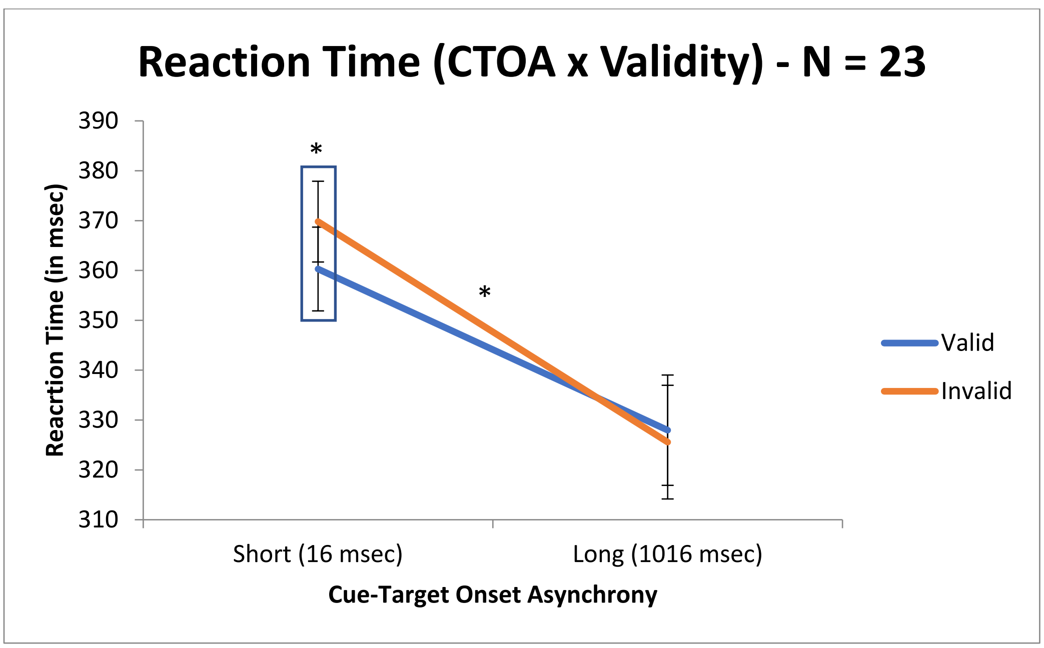


Figure 2.2. Reaction time analysis. Reaction time in target detection task (SV, SI, LV, and LI). Asterisk (*) on top of the rectangle box represents statistical significance when comparing the two conditions inside the box. In this graph, RT in SV is significantly different than ST in SI. Asterisk (*) halfway between short and long CTOA represents statistical significance for main effect of CTOA. Error bars are

average within-participant standard error.

First, there is no speed-accuracy trade-off, so we can use the RT data to investigate validity effect. Second, these results indicate that there is a significant validity effect in the short CTOA range consistent with exogenous attentional cueing. If this effect is driven by unaware exogenous cueing, we would expect to find that participants are unable to localize cue location above chance level in the cue localization task.

2.2.3.2 Cue-localization task

2.2.3.2.1 Accuracy

Table 2.1 shows mean accuracy across conditions. In both short CTOA conditions, participants perform better than chance level $t(22) = -3.43$, $p = 0.002$ and, $t(22) = 2.19$, $p = 0.040$ in valid and invalid condition respectively. Specifically, participants perform better than chance level in SI and worse than chance in SV. Meanwhile, participants did not perform better in LI than LV condition, $t(15) = -1.60$, $p = 0.12$. Participants performed at chance, $t(22) = -0.23$, $p = 0.82$ and $t(22) = 1.77$, $p = 0.09$ in both long CTOA conditions (valid and invalid) respectively.

Accuracy (%) in each condition (SV, SI, LV, LI)

		Validity	
		Valid	Invalid
CTOA	Short	35.33%	61.96%
	Long	48.91%	59.24%

Table 2.1. The accuracy in SV, SI, LV and LI (all target-present conditions) regardless of cue location (left or right) in cue-localization task.

In target-absent (NT) trials, participants perform worse than chance (*M* of accuracy = 27.17%, *SD* = 12.10%) with $t(22) = -9.12$, $p < 0.001$. which is not replicated from Mulckhuyse et al. (2007) study where they found participant performed at chance ($p = 0.89$). Since we are interested in the signal sensitivity, we will next take a look at *d'* as even with low accuracy, participants may have low false alarm, which will be accounted for in *d*' analysis.

2.2.3.2.2 Signal sensitivity (*d'*)

*

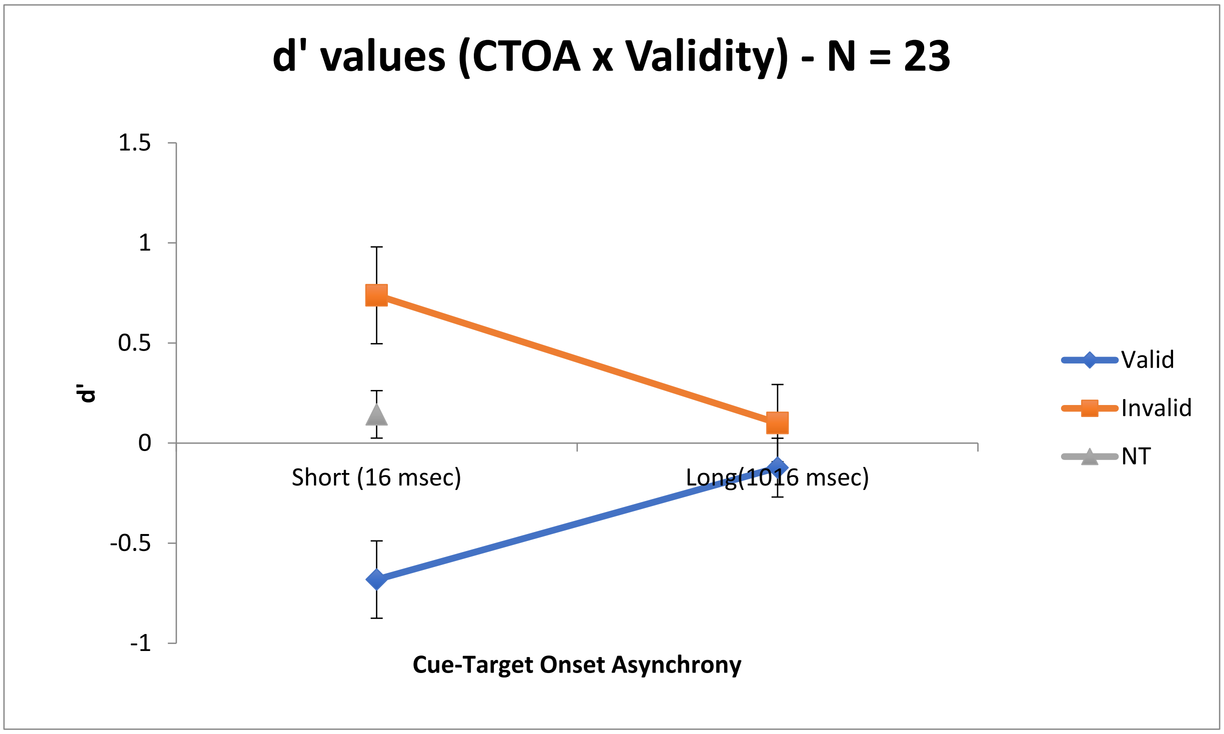


Figure 2.3. Average *d'* in our study for all conditions (SV, SI, LV, and LI) in cue-localization task. Asterisk (*) represents statistical significance ($p < 0.05$) for each respective condition when compared to $d' = 0$. The rectangle box encompassing both SV and SI conditions represent statistical significance when comparing both conditions. LV and LI are not significantly different. Error bars are average within-participant standard error.

We analyzed the results of the cue--localization task using a mixed-factors repeated measures ANOVA with Cue-Target Onset Asynchrony (2 levels; 16 or 1016 ms), and Cue Validity (2 levels; valid or invalid) as fixed effects. We modeled participant as a random effect. We found a main effect of validity showing that participants were more likely to correctly localize invalid compared to valid cues, $F(1,22) = 17.46$, $p < 0.001$, while there was no significant main effect of CTOA, $F(1,22) = 0.04$, $p = 0.84$. We found that participants were able to localize cues better than chance level SI condition, $d'_{SI} = 0.74$, $SD = 1.16$, $t(22) = 3.05$, $p = 0.006$, while in SV condition, participants performed worse than chance level, $d'_{SV} = -0.68$, $SD = 0.93$, $t(22) = -3.53$, $p = 0.019$ and at chance level in both long CTOA (LV and LI) condition, $d'_{LV} = -0.12$, $SD = 0.7$, $t(22) = -0.83$, $p = 0.41$ and $d'_{LI} = 0.1$, $SD = 0.92$, $t(22) = 0.52$, $p = 0.61$. We ran two t-tests against the null hypothesis that cue-localization sensitivity should be at chance to determine whether the valid or the invalid short CTOAs were driving the effects found in the ANOVA. We found that participants are more sensitive towards the cues in SI condition than in SV condition, $t(22) = 3.71$, $p = 0.0012$, but not in LI compared to LV condition, $t(22) = 1.13$, $p = 0.27$ (figure 2.3). This result shows the opposite pattern than in Mulckhuyse et al. (2007) (see reanalysis of Mulckhuyse et al. 2007 section).

In the NT condition, we did not find an evidence for an above-threshold cue signal, $d'_{NT} = 0.14$, $SD = 0.57$, $t(22) = 1.21$, $p = 0.24$, suggesting that in the absence of targets, participants were not able to localize the cues. On one hand, this helps Mulckhuyse's case by implying that even with non-zero d' values on both short CTOA conditions, it may be the case that participants were indeed unaware of the cues, but they used irrelevant targets that they were told to ignore as helping hands. On the other hand, it is important to note that target-absent condition is qualitatively different than short-CTOA conditions (SV and SI) in which we found validity effect and thus, we cannot conclude cue awareness based on NT condition alone.

Importantly, when collapsing our data across validity, we replicated Mulckhuyse et al. (2007)'s study (short CTOA, $d' = -0.03$, $SD = 0.46$, $t(22) = 0.28$, $p = 0.78$ and long CTOA, $d' = -0.03$, $SD = 0.70$, $t(22) = -0.22$, $p = 0.83$) as they found $d' \approx 0$ for both short and long-CTOA when collapsed across validity.

Negative d' values are theoretically troubling because, taken at face value, they indicate that the noise distribution is more salient than the signal distribution. In other words, negative *d'* values indicate that participants responded at below chance accuracy. One possibility that would yield these results would be if, in the absence of any consciously accessible knowledge of cue locations, participants discounted the instruction to ignore target position and reported that target position gave valid information about cue location. To investigate negative *d'* at valid conditions, we looked at the proportion of responses that is the same as target location in cue-localization task.

2.2.3.2.3 Response bias

In our study, in short CTOA, participants localized the cue to the same side as the target only on 36.3% of all short CTOA trials (SV, *M* = 36.1%, *SD* = 16.0%, SI, *M* = 36.4%, *SD* = 20.7%), while they localized the cue to the same side as target on 47.7% of all the long CTOA trials (LV, *M* = 47.3%, *SD* = 13.0%, LI, *M* = 48.1%, *SD* = 17.1%) (table 2.2). One possibility is that participants use the target location as a reference point for cue localization. Under the scope of this study, we cannot determine whether response bias against target location in short CTOA is intentional.

	Target location					
Condition	Left		Right		Both location	
	Mean	SD	Mean	SD	Mean	SD
Short-CTOA, Valid	0.353	0.205	0.370	0.205	**0.361**	**0.160**
Short-CTOA, Invalid	0.359	0.239	0.370	0.254	**0.364**	**0.207**
Long-CTOA, Valid	0.489	0.229	0.457	0.231	**0.473**	**0.130**
Long-CTOA, Invalid	0.554	0.250	0.408	0.251	**0.481**	**0.171**

Table 2.2 Proportion of trials in which participants localize the cues in the same location as the targets in our study, replication of Mulckhuyse et al. (2007) for each target-present condition, SV, SI, LV, and LI.

We also ran a paired-sample t-test in short CTOA (SV paired with SI, and LV paired with LI). We added each pair up as the effect of response bias in the invalid condition was mirrored from the valid condition. We found that in short CTOA, $d'_{SHORT} \approx 0$, $M = 0.03$, $SD = 0.46$, $t(22) = 0.28$, $p = 0.78$, and in long CTOA, $d'_{LONG} \approx 0$, $M = -0.03$, $SD = 0.70$, $t(22) = -0.22$, $p = 0.83$. This demonstrates that, under the assumption that response bias is equal within-participant and within-CTOA, there are no differences between cue signal sensitivity in SV and SI as well as between LV and LI. Cue signals in invalid condition are similar to those in valid condition because the difference between d'_{SI} and 0 is the same as to the difference betweem d'_{SV} and 0 (see *d'* analysis in previous section). Thus, we assume that there is no additional response bias contributing to *d'* besides the cue awareness and potential unconscious or conscious strategy revolving target location as discussed in the next paragraph.

Our findings in the cue localization task revealed that the spatial cueing effect obtained in target-detection task was not due to a boost in cue signal sensitivity in SV trials. Instead, *d'* analysis shows that participants were biased towards the cues in invalid condition, not valid condition. This beneficial effect is akin to IOR as cueing effect benefits targets in the opposite location from the cues This observed cueing effect at SI, however, is not an IOR as IOR appears at longer cue-target interval when participants were discouraged to continuously direct their attention to the cued location when the targets do not appear in cued location after a period of time. IOR begins at about CTOA of 225 ms (Klein, 2000; Posner & Cohen, 1984), though IOR may appear earlier if participants were encouraged to remove their attention from cued location (Danzinger & Kingstone, 1999). In our study's short CTOA (16 ms), there was not enough time for participants' attention to be exogenously captured and endogenously directed to the opposite location and thus, the cueing benefit obtained in target-detection task may be due to a different mechanism than IOR.

Chapter 3

Re-analysis of case studies

3.1 Mulckhuyse et al. (2007)

Since we found differential awareness of invalid over valid condition in our attempt to replicate Mulckhuyse et al. (2007) study, we reanalyzed the raw cue-localization data from the original Mulckhuyse et al. (2007) experiment and from Lin & Murray's (2013) Experiment 1 (Figure 3.1 and 5 respectively). Mulckhuyse et al.'s design for the cue localization task differed from ours in that Mulckhuyse et al. allowed participants to respond to cue location as soon as the cue was presented, regardless of the CTOA condition. Since we based our study on Mulckhuyse et al.'s the composition of each condition (SV, SI, LV, LI and NT) in both their target-detection and cue-localization tasks were the same as ours (20% for each condition of all trials). We found that in Mulckhuyse et al., participants in both valid conditions (SV and LV) were able to correctly localize cues at levels significantly above chance, using *d'* as cue signal assessment, $d'_{SV} = 1.83$, $SD = 0.75$, $t(15) = 9.73$, $p < 0.001$ and $d'_{LV} = 1.41$, $SD = 1.18$, $t(15) = 4.79$, $p < 0.001$, respectively. Meanwhile, Mulckhuyse et al.'s participants did not only performed worse at invalid condition (both short and long CTOA), but the *d'* for both invalid conditions were also negative and significantly below chance (SI, $d' = -1.67$, $SD = 0.92$, $t(15) = -7.31$, $p < 0.001$ and LI, $d' = -1.47$, $SD = 1.18$, $t(15) = -5$, $p < 0.001$). Cue localization performance in the valid and invalid trials was associated with a positive and negative *d'* (figure 3.1) respectively even though when collapsed across all Validity conditions, $d' \approx 0$, (target-absent included, short CTOA, $d' = 0.031$, $SD = 0.29$, $t(15) = 0.42$, $p = 0.68$ and long CTOA, $d' = 0.008$, $SD = 0.29$, $t(15) = 0.11$,

p = 0.92; target-absent excluded, short CTOA, d' = 0.095, SD = 0.22, $t(15)$ = 1.70, p = 0.11 and long CTOA, d' = -0.047, SD = 0.30, $t(15)$ = -0.63, p = 0.54).

We also looked at target-absent trials (20% of all trials), which double the number of trials compared to each experimental condition (10% of all trials). In the target-absent condition, participants were not able to localize the cue, $d'_{\text{target-absent}}$ = 0.025, SD = 0.27, $t(15)$ = 0.37, p = 0.71. This does provide some evidence towards SDA without awareness.

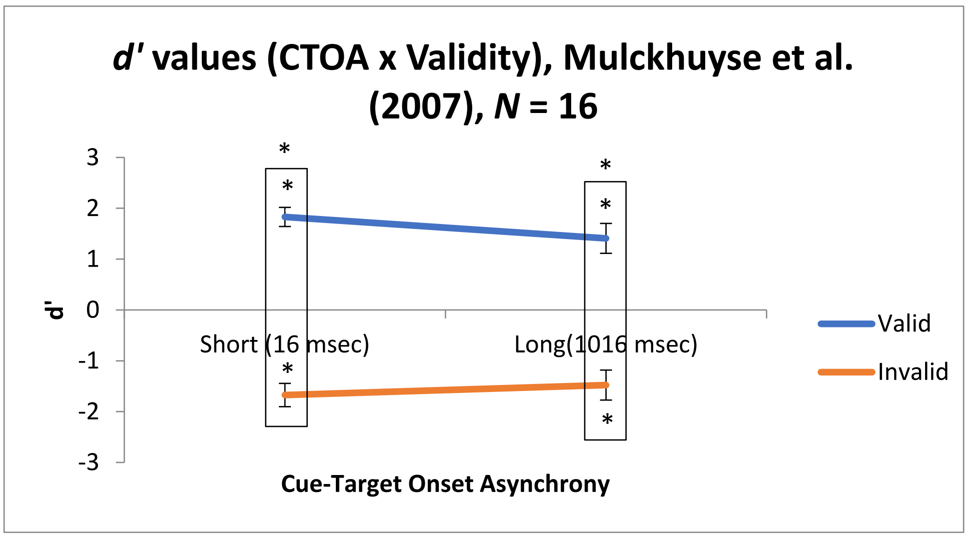


Figure 3.1. Cue signal sensitivity (d'). Reanalysis of Mulckhuyse et al. (2007) and d' are analyzed differentially for each CTOA and validity condition. Asterisks (*) on top of the rectangle box encompassing SV and SI, as well as LV and LI represents significant difference ($p < 0.05$) comparing short and long CTOA conditions respectively. Asterisks (*) on top of each condition represents significant difference compared to d' = 0. Error bars are average within-participant standard error.

3.1.1 Response bias

The data suggests that participants in Mulckhuyse's et al were more sensitive to the cue signal at valid condition, while participants in ours were more sensitive to the cue signal at invalid condition (figure 3.1), going by d' in assessing cue awareness. We then investigated the proportion of responses where participants respond with target location. The data shows that participants localized the cues on the same location as the target 83.01% of all trials (SD = 19.52%) across all conditions (see table 3.1), which provides an evidence of bias when targets were present in the trials.

Study:	Mulckhuyse et al. (2007)					
	Target location					
Condition	Left		Right		Both location	
	Mean	SD	Mean	SD	Mean	SD
Short-CTOA, Valid	0.898	0.153	0.844	0.226	**0.871**	**0.159**
Short-CTOA, Invalid	0.859	0.250	0.828	0.237	**0.844**	**0.188**
Long-CTOA, Valid	0.797	0.266	0.789	0.295	**0.793**	**0.238**
Long-CTOA, Invalid	0.836	0.245	0.789	0.298	**0.813**	**0.240**

Table 3.1 Proportion of trials in which participants localize the cues in the same location as the targets in Mulckhuyse et al. (2007) study for each target-present condition, SV, SI, LV, and LI.

Similar to the analysis of our study, we ran a paired-sample t-test in short condition (SV paired with SI, and LV paired with LI), adding each pair up as the effect response bias in invalid condition, if any, will be mirrored from the valid condition. We found that in short CTOA, $d'_{\text{SHORT}} \approx 0$, $M = 0.16$, $SD = 0.35$, $t(15) = 1.78$, p = 0.096, while in long CTOA, $d'_{\text{LONG}} \approx 0$, $M = -0.07$, $SD = 0.36$, $t(15) = -0.50$, p = 0.63. This demonstrates that, under the assumption that response bias is equal within-participant and within-CTOA and that response bias is the only other factors which contributes to *d'* besides cue signal sensitivity, there is no difference between cue signal sensitivity in SV and SI, as well as LV and LI.

3.2 Lin & Murray (2013)

We also reanalyzed Lin & Murray's (2013) cue localization data from their first experiment. Lin & Murray (2013) combined Mulckhuyse et al. (2007) and Lin (2013) study. In their study, Lin & Murray (2013) used a spatial cueing paradigm which include both retinotopic and non-retinotopic cues. In retinotopic condition, cues were located on the same side as the target, while in non-retinotopic condition, cues were located in the opposite location vertically to the target location (figure 3.2.c). First, participants did attention cueing task in which they had to respond as quickly as possible when targets appeared (black dot within one of the three black circles) (figure 3.2.a). One of the three black circles (placeholders for targets) appeared 16.7 ms or 50 ms earlier than the other two black circles, serving as abrupt onset cue. Cues were present in all trials, while the targets appeared in 80% of all trials. In the target-absent trials (20% of all trials), participants were instructed to refrain from responding.

After cueing task, participants did a cue awareness task. In the cue awareness test, participants were explicitly told to ignore the dots and focus on the circles. They were encouraged to take their time before responding to the cue spatial location.

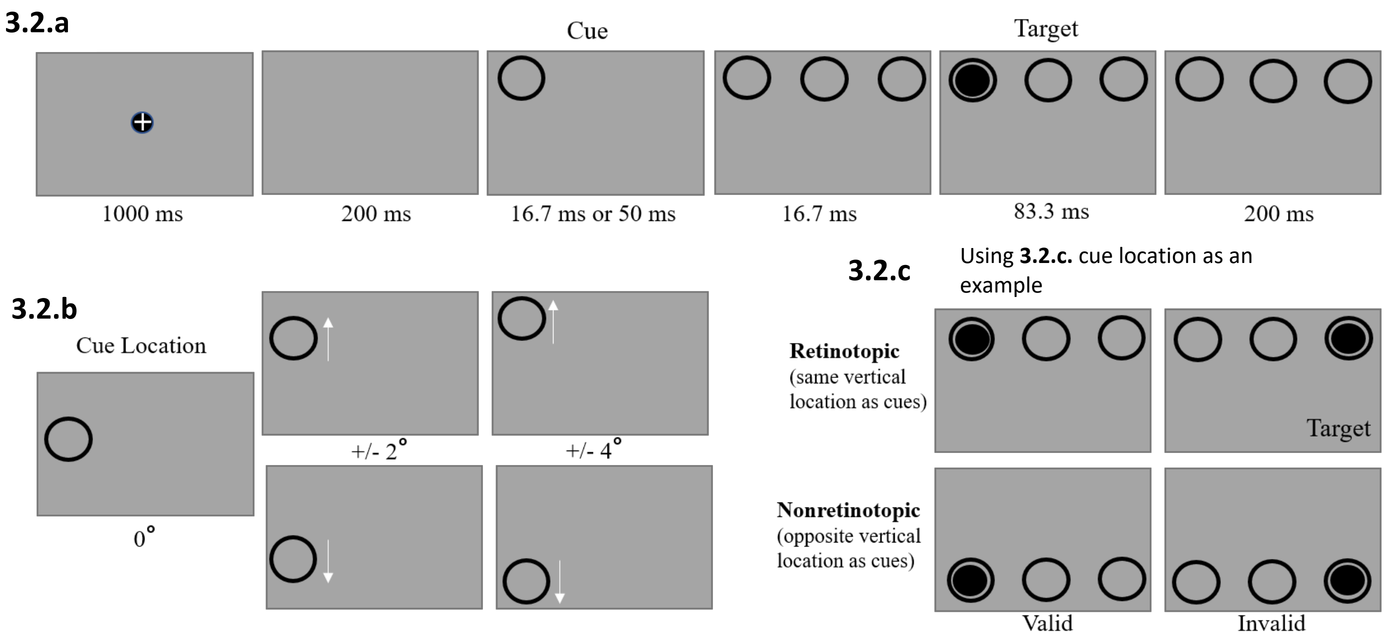


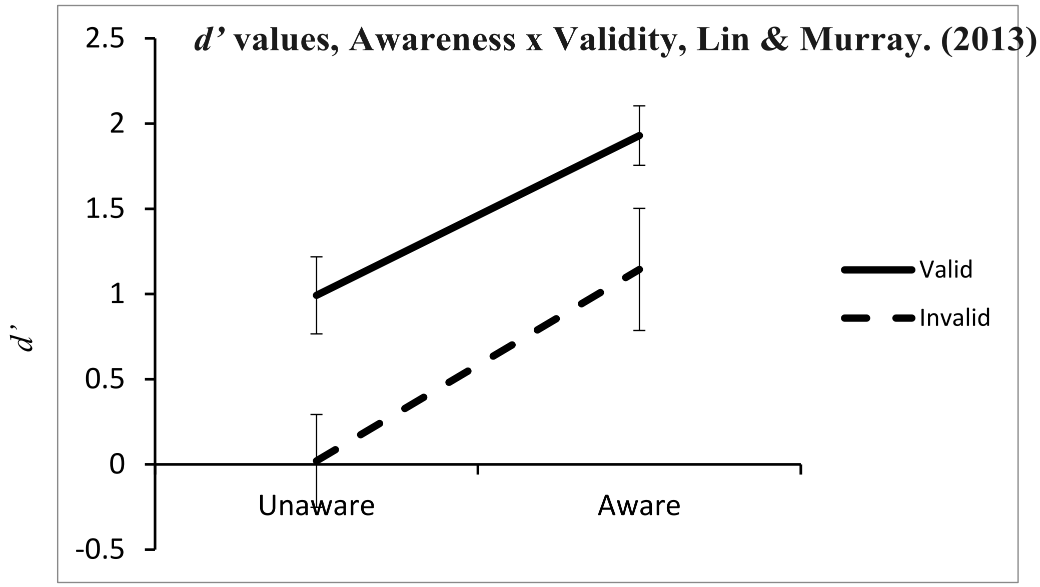
Figure 3.2. Experimental design in Lin & Murray (2013). Cues are present in all trials. Cues precedes targets in 80% of all trials. In the remaining trials (20% of all trials), there is no target. (a) Trial structure of attentional cueing task and cue awareness task. Both tasks are identical with the

exception that participants had to respond to the cues by left/right clicking mouse, while in attentional cueing, participants made a simple response once they saw the target. (b) 5 possible vertical locations of the cues (0°, +2°, -2°, +4°, and -4°). (c) 2x2 design of cue-target relationship, retinotopic valid, retinotopic invalid, non-retinotopic valid and non-retinotopic invalid.

Critically, they argued that 17 out of 31 participants in their study were not aware of the cues in unaware condition. They claimed that the cues in unaware condition were not consciously seen by their participants using d' analysis on these 17 participants, *d'* = 0.082, *SD* = 0.31, $t(16) = 1.09$, $p = 0.293$ (Lin & Murray, 2013). They applied a linear regression function (x-values represent cue visibility, d', and y-values represent cueing effect, ms) to the unaware condition and since they found positive y-intercept value, they claimed to have demonstrated exogenous cueing effect without awareness.

There are some potential issues with the study assumption and data analysis they opted to do. First, they did not account for the other 14 participants. As we demonstrated below, the overall *d'* of unaware condition is positive. This means that some abrupt onset cues in the unaware condition were perceived by some participants and arguably, the term "unaware" was not apt. Second, they collapsed *d'* across validity factor. From our study and Mulckhuyse et al. (2007), we found that validity factor introduces interesting interaction between CTOA and validity factor. Thus, it is not far-reaching to investigate the effect of validity on cue awareness in Lin & Murray (2013). Third, while it is true that y-intercept value corresponds to x = 0, which means *d'* = 0, linear regression function factors in the values across all cue visibility range. This means that the intercept value is also affected by the positive or negative *d'* values. In other words, a demonstration of SDA is contaminated by positive or negative *d'*.

We are now going to reanalyze their data by including all their participants in cue awareness and by separating the data into valid and invalid categories like we did with Mulckhuyse et al. (2007). We collapsed their data across all vertical locations (0°, +/- 2°, and +/- 4°, figure 3.2.b) according to the validity of the cues. This gave us enough trials to compute *d'* measures, and is justified because their primary goal in the experiment is to show that the attentional orienting effect of their cues do not only apply to the cue location, but can also apply translationally to object-centered location which is where the target (black dot) is. In Lin & Murray (2013), the cues had an attentional orienting effect on the targets despite their different location because participants perceive the three black circles (figure 3.2.a) as a dynamic system that travels with apparent motion (Lin, 2013) and considered to be the same object (e.g. left-placed circle at 0 degree "travels" or moves up to the left-placed circle at +2 degree. Thus, different vertical locations under the same validity and duration of cues (unaware and aware) can be analyzed under one condition. Here, we found that in the putatively unaware condition, valid cues (unaware valid, UV) were localized with above chance accuracy, $d' = 0.99$, $SD = 1.26$, $t(30) = 4.39$, $p < 0.001$. Unlike in Mulckhuyse et al. (2007), *d'* of unaware invalid (UI) were not significantly different than chance, $d' = 0.021$, $SD = 1.52$, $t(30) = 0.076$, $p = 0.94$. Due to long presentation of cues in aware condition (aware valid, AV, and aware invalid, AI), their findings of positive *d'* (AV, $d' = 1.93$, $SD = 0.97$, $t(30) = 11.05$, $p < 0.001$ and AI, $d' = 1.14$, $SD = 1.99$, $t(30) = 3.19$, $p = 0.003$) were expected and not relevant to our discussion (figure 3.3).



Awareness Condition

Figure 3.3. Cue signal sensitivity (*d'*). Reanalysis of Lin & Murray (2013) and *d'* are analyzed differentially for each CTOA and validity condition. Asterisk (*) on rectangle box encompassing both unaware conditions represent statistical significance when both unaware conditions are compared. Asterisks (*) on top of each condition (Unaware-valid, aware-valid, aware-invalid) represents significant difference compared to *d'* = 0. Error bars are average within-participant standard error.

Taken together, the cue-localization sensitivity biases found in the Mulckhuyse et al. (2007) that we re-analyzed and the bias found in our experiment are distinct as not only our data show an opposite pattern to Mulckhuyse et al. (2007) study, but we also obtain a combined $d' > 0$ when collapsing across validity condition, ($d' = 0.24$, $SD = 0.30$, $t(15) = 3.24$, $p = 0.005$ for short CTOA and $d' = 0.31$, $SD = 0.50$, $t(15) = 2.53$, $p = 0.023$ for long CTOA) respectively. In Lin & Murray's (2013), we also found that in valid condition, the $d' > 0$, with a $d' = 0$ in short-CTOA invalid condition. This suggests that in Lin & Murray (2013)'s study design, participants might be aware of the cues in SV, but not SI condition. Also, for reasons mentioned in previous paragraph, Lin & Murray (2013) claim of SDA may not be warranted. In their regression analysis, they included all *d'* from all participants, and found the y-intercept. This means that the regression analysis includes participants who were aware of the cues, and this would contaminate the analysis.

Based on our study findings, we cannot claim SDA without conscious awareness based on incomplete analysis of *d'*, such as in Mulckhuyse et al. (2007) and Lin & Murray (2013), without accounting for the validity effects. This study demonstrates that other factor, such as response bias can take place in some experiments and the resulting *d'* of 0 that Mulckhuyse et al. (2007) was due to balancing positive and negative *d'* in valid and invalid condition respectively. Though this does not provide evidence against the claim of SDA without awareness per se, the *d'* obtained was not purely 0 and combined with the conflicted findings in our study, one may need to adjust the justification given for SDA without awareness.

Chapter 4

Discussion

4.1 Discussion

In this study, we have demonstrated that in a previously published paradigm, claims of stimulus-driven attention without awareness may have been based on an incomplete analysis of awareness measurements or a study design that does not address the possibility of response bias.

In Lin & Murray (2013), we believe that there are two factors that could account for differential cue awareness in valid than invalid condition in unaware condition, especially on valid trials with overlapping location. First, the cued retinal location receives more stimulus-energy than the two-placeholder locations. In other words, the 16.7 ms lead-time conferred on the cued location is well within the range of linear temporal luminance summation (Bloch, 1885). In valid, overlapping condition, the cue period is immediately followed by the placeholders or placeholders-plus-target screen with no blanking period between the two, and thus, the amount of luminance at the cued location sums, leading to greater neural activation at the cortical location corresponding to the cue's retinal position. However, in valid, non-retinotopic condition, the signals from the abrupt onset cues potentially do not confer as much increase in cortical activation as in valid, overlapping condition. Still, when the target is presented at the same location or on the same side (non-retinotopic) as the cue, the corresponding cortical activation is already elevated and participants are able to respond more quickly (LaBerge, 1995, 2001; Lamme, 2003; Lin, 2013). By contrast, when the target is presented opposite the cue, the sudden onset of the target draws stimulus-driven attentional resources away from the primed location (Jonides & Irwin, 1981; Posner, 1980; Posner, Walker, Friedrich, & Rafal, 1984; Yantis & Jonides, 1984), allowing the perceptual trace left by the cue to fade before rising to the threshold of awareness.

Secondly, several researchers (Anstis, 1970; Georgeson & Georgeson, 1985; Lappin & Disch, 1972; Smith, Howell, & Stanley, 1982) have demonstrated rapid temporal information processing within the visual system. Indeed, the temporal resolution of order detection for stimuli that are not defined by inter-stimulus luminance differences is estimated at approximately 20 ms (Hirsh & Sherrick, 1961) and is relatively robust when the visual angle separating the stimuli is between 5º to 20º degrees (c.f. (Westheimer & McKee, 1977); see Blake & Lee, 2005 for review). In Lin & Murray (2013)'s study, experiment 1 presents the cue and placeholder stimuli at a 16.7 ms lag, placing the CTOA just short of the estimated threshold of temporal order resolution. Another evidence in support of differential cue awareness in valid but not invalid cue-target conditions is the electrophysiological study by Giattino and colleagues (2018). They showed that an event-related potential (ERP) index of early sensory processing of target stimuli, P1, was more enhanced in validly cued than invalidly cued conditions when participants were unaware of the cue, demonstrating a bias of low-level sensory processing for valid trials in unaware cue location. These two factors above may raise the perceptual trace of the short CTOA valid cue above threshold for conscious perception.

With regards to Mulckhuyse et al. (2007) reanalyzed data, there is a plausible reason why participants' responses gravitated towards the target location when localizing the cues in cue-localization task. This could be due to retro-perception, in which post-target visual cues may direct attention towards cue location and raise supposedly unseen cues past the threshold of consciousness (Sergent, 2018; Thibault et al. 2015). In the context of Mulckhuyse's cue localization task, a retroactive cueing effect could be triggered by the targets when the cue was previously shown on the same side, thus bringing the cue location to awareness.

It is also possible that Mulckhuyse et al. participants were, as Mulckhuyse and colleagues claimed, not aware of the 16 ms cues, but were biased to respond to the same location as the target, which resulted in positive and negative *d'* in valid and invalid trials respectively. If the reason for positive *d'* in Mulckhuyse SV condition is indeed due to retro-perception (Sergent, 2018), then the cue signal sensitivity in short-CTOA valid condition for the cues should be increased, after removing the response bias effect. In other words, d'_{SV} +

$d'_{SI} > 0$ (assuming one d' is positive and the other is negative; if both are positives or negatives, retro-perception would mean $|d'_{SV} - d'_{SI}| > 0$), but we found that $d'_{SV} + d'_{SI} \approx 0$. Thus, the response bias hypothesis without cue awareness is more likely than retro-perception cue signal boost on top of response bias.

By contrast in our study, we found that participants were likely to localize the cues opposite to the target location in both short CTOA and not in long CTOA. Consequently, our study findings weaken the argument for retro-cue awareness because if targets were to function as retro-cues and provide boosts to cue signal strength, cue signal sensitivity in valid condition should be increased, even if participants were biased to respond to the opposite location in our study. This means that the participants should be more aware (marked by increase in *d'*) of the cues in valid condition according to retro-cue perception hypothesis. However, as we mentioned in results section, *response bias effect* in SI (how much *d'* deviates from 0) is similar to the *response bias effect* in SV, while under retro-cue perception hypothesis we should expect a larger *response bias effect* in SV than *response bias effect* in SI. Thus, our study, like Mulckhuyse et al.'s also goes against the retro-cue hypothesis, albeit showing completely opposite pattern with regards to the validity of the cues.

As mentioned earlier in Method section, our study was slightly modified from Mulckhuyse et al. (2007) so that our cue-localization task was structured in the same way as the target-detection task. Specifically, Mulckhuyse et al. (2007) allows participants to respond as soon as they perceived the cues, while in our study, they had to wait for 200 ms after target offset before responding. At first blush, this change of instruction seems to influence the result of our cue localization task as it is the only procedural design between the two studies. At closer look, however, the procedural difference between our study and Mulckhuyse et al. (2007) may not be significant enough to have caused the behavioral differences that we observed. Even if Mulckhuyse's participants were allowed to respond as quickly as they could, they would still respond after 200 ms in 99.06% of all trials. Only a total of 12 trials across all 16 participants have a response below 200 ms. This means that our study's "waiting" period before the response prompt was not long enough to significantly affect participant's RT in short-CTOA. Put differently, participants in Mulckhuyse et al. (2007) still needed more than 200 ms to respond and thus, at 0 ms cue-target interval, participants in our study and Mulckhuyse et al. (2007) saw the same stimuli between the cue onset and target offset.

Additionally, there are also some minor differences in stimulus presentation between Mulckhuyse et al. (2007) and our study. The placeholders in Mulckhuyse et al. (2007) were 1.9° in diameters, while in our study, the diameters were 2.6°. The distance from the center of middle placeholders and the center of the left or right placeholders was 6.7° in Mulckhuyse et al.'s (2007), while that of our study was 9.2°. These differences in stimulus presentation, however, did not affect response bias as we found none. Let's imagine the larger visual angle of our study between placeholders increase the difficulty to perceive the cue, we should expect a decrease of *d'* in NT condition. However, we found similar *d'* in NT trials. Participants in our study performed similarly than those in Mulckhuyse et al.'s, indicating that the effect of stimulus presentation may be minor. Meanwhile, we did find opposite pattern in which participants were biased to localize cues in different direction, towards or away from the target. However, this minor differences in stimulus difference cannot explain the flip in response bias.

I concede that within the confine of our study, I cannot explain how we found the opposite pattern of *d'*s than those in Mulckhuyse et al. (2007). Surely, as discussed in an earlier paragraph, retro-perception is unlikely to explain how in our study's valid condition, the cue signal was worse, not better. Nonetheless, all concerns raised above point towards the need to come up with a better study design before one can claim SDA without awareness.

Our data further cements the need for a better alternative study design. How does the validity cueing effect was obtained in our study's target detection task when participants were not aware of the cues in SV condition? In fact, the *d'* analysis of our study seems to demonstrate that participants were biased against target location such that in SI condition, they had more hits and consequently fewer false alarms, while in SV, they had less hits and higher false alarms. As we explored in earlier sections, *d'* obtained in the analyses seem to be strongly driven by response bias, in addition to the participant's awareness level of the cues. Also relevant to our discussion on claims for SDA without awareness, since participants were not explicitly told about the cue existence in the target-detection task which they did before cue-localization task, the result of the cue-localization task may not represent how the cues were actually perceived, or not perceived, in the target-detection task. Put another way, the results we obtained in our cue-localization task may not be how these cues were actually perceived in the target-detection task. This could be the reason why we obtained negative *d'* in SV condition on cue localization task, even when there was a spatial cueing benefit in SV on target detection task.

Chapter 5

Future research and conclusion

5.1 Future research

We started this study to replicate an experiment, which is widely cited and used as an evidence towards SDA without awareness and we were not able to replicate that study. In fact, we even found an opposite pattern of *d'* from the reanalysis of the original study by Mulckhuyse et al. (2007).

I propose a follow-up experiment that can address the possibility of response bias towards (in the case of Mulckhuyse et al.'s study) or against (in the case of our study) the target location when participants were not aware of the cues. In this study, the procedures are the same as in Mulckhuyse et al. (2007) and our study. The only difference is the inclusion of trials without cues (cue-absent condition) in cue-localization task and by extension, target-detection task. Targets are still present in some trials and absent in the remaining trials.

With the above-mentioned experimental design, and analysis of target-absent trials (with or without cues), we should be able to assess how participants perceive the briefly presented cues. The advantage of this new experimental design over our current experiment is that it allows the analysis of cue-present and cue-absent trials in the same experiment. If participants are not able to localize the cues in no-target trials, we are able to demonstrate that participants are indeed unaware of the cues if they are presented alone without targets. First, I expect a $d' \approx 0$ in cue-absent, target-absent condition, which serves as a control. Second, I expect $d' > 0$ or $d' < 0$ in cue-absent, target present condition depending on which study design is used (Mulckhuyse et al. or ours) and based on CTOA and Validity. A replication of *d'* pattern would demonstrate our response bias hypothesis. Lastly, since we obtained *d'* ≈ 0 in Mulckhuyse et al. (2007) in NT condition and *d'* ≈ 0 in our study's NT condition, I would expect the same pattern in cue-present, target-absent (NT) condition depending on which study design is used, though as I conceded earlier, the difference in experimental design is so minute it should not result in the opposite pattern for both short CTOA, and long CTOA to a lesser degree. .

As a word of caution, even if we obtain *d'* ≈ 0 in cue-present, target-absent trials, it still does not provide clear evidence of SDA without awareness. The validity effect found in any form of spatial cueing paradigm is not only because of the cue presence, but could also involve the interaction between the cues and the targets. This has been demonstrated in our study as targets seem to bias responses to a certain location. Thus, in target-absent trials, one cannot strongly claim evidence of the unaware nature of cues looking at *d'* in target-absent condition. Indeed, Mulckhuyse and colleagues did not use *d'* in their NT to claim non-awareness of the cues, and neither should we. An analysis of cue awareness should reliably take into account any response bias in the absence of cues. If there exists a response bias in cue-absent condition, and we subtract this bias from the cue-present condition, we then have a pure cue awareness assessment and this provides a stronger evidence to the claim of unconscious awareness of cues.

Additionally, I would like to propose an additional survey at the end of experiment to inquire participants on their strategy in cue-localization task. If response bias persists and participants indicate that they do not use targets as a point of reference, then the response bias is unintentional. If response bias is intentional, participants' response to the survey would reveal such intention.

It stands to reason that our analysis of the effect of cue validity on awareness may apply to papers other than Mulckhuyse et al.'s (2007) and Lin & Murray (2013) that have investigated SDA without awareness with the spatial cueing paradigm (e.g. Schettino et al., 2016; Schoeberl et al., 2015; Schoeberl & Ansorge, 2018) because they did not take into account the possibility of response bias in absence of awareness and did not investigate how *d'* interacts with validity factor.

5.2 Conclusion

Taken together with our critical review of the literature, our findings lead us to the conclusion that there is, as of yet, no compelling evidence that SDA can occur without awareness. The chance-level performance in cue-localization task Mulckhuyse et al. (2007) reported was from mirroring positive and negative values of *d'* and not from pure 0 *d'*. Similarly, many studies mentioned in previous paragraph did not differentially analyze *d'* as they collapsed the data across all validity conditions. With regards to Lin & Murray (2013) study, we did find some evidence towards cue signal boost only in valid condition. Overall, in light of our study and reanalysis of the two studies claiming SDA without awareness (Mulckhuyse et al., 2007 and Lin & Murray, 2013), cue awareness is more nuanced than *d'* analysis collapsed across validity factors. This is not to say that some form of orienting does not occur without awareness. For example, Rothkirch et al. (2012) demonstrated goal-directed oculomotor orienting towards targets in the objective absence of awareness of the target's location. Our criticism concerns stimulus-driven orienting. It may very well be that future clever experimental designs will provide even more compelling evidence for SDA without awareness. We wager that such studies will have ruled out a role of cue validity and response bias in accounting for their findings.

References

Anstis, S. M. (1970). Phi movement as a subtraction process. *Vision Research, 10*(12), 1411-1430.
Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/5516541

Asplund, C. L., Fougnie, D., Zughni, S., Martin, J. W., & Marois, R. (2014). The attentional blink reveals the probabilistic nature of discrete conscious perception. *Psychological Science, 25*(3), 824-831. doi:10.1177/0956797613513810

Awh, E., Belopolsky, A.V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in cognitive sciences, 16*(8), 437-443.

Bargh, J. A. (1992). The ecology of automaticity: toward establishing the conditions needed to produce automatic processing effects. *American Journal of Psychology, 105*(2), 181-199. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1621880

Bayliss, A. P., & Tipper, S. P. (2005). Gaze and arrow cueing of attention reveals individual differences along the autism spectrum as a function of target context. *British Journal of Psychology, 96*(Pt 1), 95-114. doi:10.1348/000712604X15626

Berlucchi, G. (2006). Inhibition of return: A phenomenon in search of a mechanism and a better name. *Cognitive neuropsychology, 23*(7), 1065-1074.

Blake, R. (1989). A neural theory of binocular rivalry. *Psychological Review,* 96(1), 145.

Blake, R., & Lee, S. H. (2005). The role of temporal structure in human vision. *Behavioral and Cognitive Neuroscience Reviews, 4*(1), 21-42. doi:10.1177/1534582305276839

Bloch, A. (1885). Experiences sur la vision. *CR Seances Soc. Biol. Paris, 37*, 493-495.

Bonneh, Y.S., Cooperman, A. & Sagi, D. (2001). Motion-induced blindness in normal observers. *Nature, 411*(6839), 798-801.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spat Vis, 10*(4), 433-436. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9176952

Charlton, S. G., & Starkey, N. J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 14*(6), 456-471. doi:10.1016/j.trf.2011.04.010

Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *40*(4), 343.

Chica, A. B., Lupiáñez, J., & Bartolomeo, P. (2006). Dissociating inhibition of return from endogenous orienting of spatial attention: Evidence from detection and discrimination tasks. *Cognitive neuropsychology, 23*(7), 1015-1034.

Chica, A. B., Martin-Arevalo, E., Botta, F., & Lupianez, J. (2014). The Spatial Orienting paradigm: how to design and interpret spatial attention experiments. *Neuroscience and Biobehavioral Rev, 40*, 35-51. doi:10.1016/j.neubiorev.2014.01.002

Chong, S.C., & Blake, R. (2006). Exogenous attention and endogenous attention influence initial dominance in binocular rivalry. *Vision research, 46*(11), 1794-1803.

Chun, M. M., Golomb, J. D., & Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annual Review of Psychology, 62*, 73-101. doi:10.1146/annurev.psych.093008.100427

Corbetta, M. & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature reviews neuroscience 3*(3), 201-215.
Danziger, S. & Kingstone, A. (1999). Unmasking the inhibition of return phenomenon. *Perception & Psychophysics. 61*(6), 1024-1037.
Eriksen, B. A., Eriksen, C. W., & Hoffman, J. E. (1986). Recognition memory and attentional selection: serial scanning is not enough. *Journal of Experimental Psychology: Human Perception and Performance, 12*(4), 476-483. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2946804
Fang, F. & He, S. (2005). Cortical responses to invisible objects in the human dorsal and ventral pathways. *Nature neuroscience, 8*(10). 1380-1385.
Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1030.
Friesen, C. K., & Kingstone, A. (2003a). Abrupt onsets and gaze direction cues trigger independent reflexive attentional effects. *Cognition, 87*(1), B1-10. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12499107
Friesen, C. K., & Kingstone, A. (2003b). Covert and overt orienting to gaze direction cues and the effects of fixation offset. *NeuroReport, 14*(3), 489-493. doi:10.1097/01.wnr.0000058776.36017.5d
Friesen, C. K., Moore, C., & Kingstone, A. (2005). Does gaze direction really trigger a reflexive shift of spatial attention? *Brain and Cognition, 57*(1), 66-69. doi:10.1016/j.bandc.2004.08.025
Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional effects of counterpredictive gaze and arrow cues. *J Journal of Experimental Psychology: Human Perception and Performance, 30*(2), 319-329. doi:10.1037/0096-1523.30.2.319
Fuchs, I., & Ansorge, U. (2012). Inhibition of return is no hallmark of exogenous capture by unconscious cues. *Frontiers in Human Neuroscience, 6*, 30. doi:10.3389/fnhum.2012.00030
Galdi, S., Cadinu, M., & Tomasetto, C. (2014). The roots of stereotype threat: when automatic associations disrupt girls' math performance. *Child Development, 85*(1), 250-263. doi:10.1111/cdev.12128
Georgeson, M. A., & Georgeson, J. M. (1985). On seeing temporal gaps between gratings: a criterion problem for measurement of visible persistence. *Vision Research, 25*(11), 1729-1733. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3832597
Giattino, C. M., Alam, Z. M., & Woldorff, M. G. (2018). Neural processes underlying the orienting of attention without awareness. *Cortex, 102*, 14-25.
Han, S. W., & Marois, R. (2014). Functional fractionation of the stimulus-driven attention network. *J Neurosci, 34*(20), 6958-6969. doi:10.1523/JNEUROSCI.4975-13.2014
Hirsh, I. J., & Sherrick, C. E., Jr. (1961). Perceived order in different sense modalities. *Journal of Experimental Psychology, 62*, 423-432. Retrieved fromhttp://www.ncbi.nlm.nih.gov/ pubmed/13907740
Hommel, B., Pratt, J., Colzato, L., & Godijn, R. (2001). Symbolic control of visual attention. *Psychological Science, 12*(5), 360-365. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11554667
Ivanoff, J., & Klein, R. M. (2003). Orienting of attention without awareness is affected by measurement-induced attentional control settings. *Journal of Vision, 3*(1), 32-40.

doi:10:1167/3.1.4
James, W. (1890). The principles of psychology (Vol. 1). *New York: Holt*.
Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. *Attention and performance, IX*, 187-203.
Kim, C. Y., & Blake, R. (2005). Psychophysical magic: rendering the visible 'invisible'. *Trends in cognitive sciences, 9*(8), 381-388.
Klein, R.M. (2000). Inhibition of return. *Trends in Cognitive Sciences 4*(4), 138-147
Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science, 10*(4), 346-352.
Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. *Philosophical Transactions of Royal Society London B: Biological Sciences, 362*(1481), 857-875. doi:10.1098/rstb.2007.2093
LaBerge, D. (1995). *Attentional processing: The brain's art of mindfulness* (Vol. 2): Harvard University Press.LaBerge, D. (2001). Attention, consciousness, and electrical wave activity within the cortical column. *International journal of psychophysiology, 43*(1), 5-24.
Laidlaw, K. E. W., & Kingstone, A. (2017). If not when, then where? Ignoring temporal information eliminates reflexive but not volitional spatial orienting. *Vision 1*, 12. doi:10.3390/vision1020012
Lakin, J. L. (2006). Automatic cognitive processes and nonverbal communication. *The Sage handbook of nonverbal communication*, 59-77.
Lamme, V. A. (2003). Why visual attention and awareness are different. *Trends Cogn Sci, 7*(1), 12-18. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12517353
Lappin, J. S., & Disch, K. (1972). The latency operating characteristic. II. Effects of visual stimulus intensity on choice reaction time. *J Exp Psychol, 93*(2), 367-372. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/5025741
Lin, J. Y., Murray, S. O., & Boynton, G. M. (2009). Capture of attention to threatening stimuli without perceptual awareness. *Current Biology, 19*(13), 1118-1122. doi:10.1016/j.cub.2009.05.021
Lin, Z. (2013). Object-centered representations support flexible exogenous visual attention across translation and reflection. *Cognition, 129*(2), 221-231.
Lin, Z., & Murray, S. O. (2013). Visible propagation from invisible exogenous cueing. *Journal of Vision,*13(11):12,1–15 doi:10.1167/13.11.12
Lin, Z., & Murray, S. O. (2014). Priming of awareness or how not to measure visual awareness. *Journal of Vision, 14*(1):27, 1-17. doi:10.1167/14.1.27
Lin, Z., & Murray, S. O. (2015). More power to the unconscious: conscious, but not unconscious, exogenous attention requires location variation. *Psychological Science, 26*(2), 221-230. doi:10.1177/0956797614560770
Liu, X., Crump, M. J., & Logan, G. D. (2010). Do you know where your fingers have been? Explicit knowledge of the spatial layout of the keyboard in skilled typists. *Memory & Cognition, 38*(4), 474-484. doi:10.3758/MC.38.4.474
Logan, G. D. (1988). Automaticity, resources, and memory: theoretical controversies and practical implications. *Human Factors, 30*(5), 583-598. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3065212
Logan, G.D. (2018). Automatic control: How experts act without thinking. *Psychological Review, 125*, 453-485.

Logan, G. D., & Crump, M. J. (2009). The left hand doesn't know what the right hand is doing: the disruptive effects of attention to the hands in skilled typewriting. *Psychological Science, 20*(10), 1296-1300. doi:10.1111/j.1467-9280.2009.02442.x

Marotta, A., Lupianez, J., Martella, D., & Casagrande, M. (2012). Eye gaze versus arrows as spatial cues: two qualitatively different modes of attentional selection. *Journal of Experimental Psychology: Human, Perception and Performance, 38*(2), 326-335. doi:10.1037/a0023959

Martin-Arevalo, E., Kingstone, A., & Lupianez, J. (2013). Is "Inhibition of Return" due to the inhibition of the return of attention? *Quarterly Journal of Experimental Psychology (Hove), 66*(2), 347-359. doi:10.1080/17470218.2012.711844

McCormick, P. A. (1997). Orienting attention without awareness. *Journal of Experimental Psychology : Human, Perception and Performance, 23*(1), 168-180. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9157183

Merikle, P. M., & Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Consciousness and Cognition, 6*(2-3), 219-236. doi:10.1006/ccog.1997.0310

Moors, A. (2016). Automaticity: Componential, Causal, and Mechanistic Explanations. *Annual Reviews of Psychology, 67*, 263-287. doi:10.1146/annurev-psych-122414-033550

Mulckhuyse, M., Talsma, D., & Theeuwes, J. (2007). Grabbing attention without knowing: Automatic capture of attention by subliminal spatial cues. *Visual Cognition, 15*(7), 779-788. doi:10.1080/13506280701307001

Nakayama, K. & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision research, 29*(11), 1631-1647.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spatial Vision, 10*(4), 437-442. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9176953

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology, 32*(1), 3-25. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7367577

Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review, 78*(5), 391-408. doi:10.1037/h0031333

Posner, M.I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bouwhuis (Eds.), *Attention and Performance* (Vol. X, pp. 531-556). London, UK: Erlbaum.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive neuropsychology, 2*(3), 211-228.

Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience, 4*(7), 1863-1874. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6737043

Remington, R., & Pierce, L. (1984). Moving attention: evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics, 35*(4), 393-399. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6739275

Rothkirch, M., Stein, T., Sekutowicz, M., & Sterzer, P. (2012). A direct oculomotor correlate of unconscious visual processing. *Current Biology, 22*(13), R514-515. doi:10.1016/j.cub.2012.04.046

Sato, W., Okada, T., & Toichi, M. (2007). Attentional shift by gaze is triggered without awareness. *Experimental Brain Research, 183*(1), 87-94. doi:10.1007/s00221-007-1025-x

Schettino, A., Rossi, V., Pourtois, G. & Müller, M. M. (2016). Involuntary attentional orienting in the absence of awareness speeds up early sensory processing. *Cortex, 74*, 107-117. https://dx.doi.org/10.1016/j.cortex.2015.10.016

Schoeberl, T., & Ansorge, U. (2018). The impact of temporal contingencies between cue and target onset on spatial attentional capture by subliminal onset cues. *Psychological Research*, 1-10. https://doi.org/10.1007/s00426-018-1001-z.

Schoeberl, T., Fusch, I., Theeuwes, J., & Ansorge, U. (2015). *Stimulus-driven attentional capture by subliminal onset cues. Attention, Perception, & Psychophysics, 77*(3), 737-748. https://doi.org/10.3758/s13414-014-0802-4.

Sergent, C. (2018). *The offline stream of conscious representations. Philosophical Transactions of the Royal Society B : Biological Sciences. 373*(1755), 20170349.

Simons, D. J. (2000). Attentional capture and inattentional blindness. *Trends in Cognitive Sciences, 4*(4), 147-155. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10740279

Smith, G., Howell, E. R., & Stanley, G. (1982). Spatial frequency and the detection of temporal discontinuity in superimposed and adjacent gratings. *Perception & Psychophysics, 31*(3), 293-297. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7088674

Snyder, K. M., Ashitaka, Y., Shimada, H., Ulrich, J. E., & Logan, G. D. (2014). What skilled typists don't know about the QWERTY keyboard. *Attention, Perception, & Psychophysics, 76*(1), 162-171. doi:10.3758/s13414-013-0548-4

Swets, J. A. (1961). Is there a sensory threshold? *Science, 134*(3473), 168-177. Tanner, W. P., Jr., & Swets, J. A. (1954). A decision-making theory of visual detection. *Psychological Review, 61*(6), 401-409. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/13215690

Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception and Psychophysics, 49*, 83-90.

Theeuwes, J., Kramer, A., Hahn, S., & Irwin, D. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science, 9*, 379-385.

Thibault, L., Van den Berg, R. Cavanagh, P., & Sergent, C. (2016). Retrospective attention gates discrete conscious access to past sensory stimuli. *PLoS One, 11*(2).

Tiffany, S. T. (1990). A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review, 97*(2), 147-168. doi:10.1037/0033-295x.97.2.147.

Tong, F., Meng, M. & Blake, R. (2006). Neural bases of binocular rivalry. *Trends in Cognitive Sciences, 10*(11), 502-511.

Tsuchiya, N., Koch, C., Gilroy, L.A., & Blake, R. (2006). Depth of interocular suppression associated with continuous flash suppression, flash suppression, and binocular rivalry. *Journal of vision, 6*(10), 6-6.

Verleger, R., vel Grajewska, B. Ż., & Jaśkowski, P. (2012). Time-course of hemispheric preference for processing contralateral relevant shapes: P1pc, N1pc, N2pc, N3pc. *Advances in Cognitive Psychology, 8*(1), 19-28.

Westheimer, G., & McKee, S. P. (1977). Perception of temporal order in adjacent visual

stimuli. *Vision Research, 17*(8), 887-892. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/595393
Wolfe, J. M. (1994). Visual search in continuous, naturalistic stimuli. *Vision research, 34*(9), 1187-1195.
Wright, R. D., & Ward, L. M. (2008). *Orienting of attention*: Oxford University Press.
Yantis, S. (2000). Goal-directed and stimulus-driven determinants of attentional control. In S. D. Monsell, J. (Ed.), *Attention and performance* (Vol. 18, pp. 73-103). Cambridge, MA: MIT Press.
Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10*(5), 601-621. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6238122