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Observations on Facilitation and IOR in the Posner Paradigm

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Abstract

In the Posner paradigm (Posner & Cohen, 1984), participants respond to a visual target preceded by a peripheral cue, either for a short or long stimulus onset asynchrony (SOA), and either at the same or a different location (Validity). Participants respond more quickly to targets when the target is cued by a stimulus at the same location for short SOAs (facilitation). This effect reverses for longer SOAs (Inhibition of Return, IOR). Previous research reported that the magnitude of facilitation and IOR was affected by physical characteristics of the cues (e.g., Lambert & Hockey, 1991; Pratt, Hillis, & Gold, 2001) and the targets (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996) in the COVAT paradigm.

This thesis investigated the effect of physical characteristics of cues and targets and double cueing on facilitation and IOR. Exp. 1 aimed to examine the cue-target discriminability by manipulating the novelty of cues and targets. I found IOR but no facilitation. In addition, the cue-target discriminability did not affect the IOR, which was in line with the conclusion suggested by Pratt and colleagues (2001). In Exp. 2 I examined the effect of presenting onset and offset cues on facilitation and/ or IOR in different sequences of appearing and disappearing cues, labelled on-off and off-on cues. For on-off cueing, I found IOR but no facilitation. For off-on cueing, I found facilitation and no IOR for off-on cueing. This suggests that compared to on-off cues, off-on cues work more effectively in terms of capturing attention and that off-on cues can eliminate the otherwise robust IOR effect. In addition, for short SOA, the cue delayed the target detection for on-off cues but not for on-off cues. In Exp. 3A I examined the effects of the cue and target size on facilitation and IOR. IOR was found for both the small and large condition. Size did therefore not affect IOR for the long SOA. Facilitation was not found for either the small or large condition and instead, early IOR was found for the short SOA in the small size condition. In Exp. 3B I investigated the effect of changes in cue size on facilitation and IOR, using static cues similar to Exp. 3A as controls. I found no facilitation but observed IOR. Increased IOR was found for small cues compared to large cues in the static cue conditions. In Exp. 4A and Exp. 4B I used a double-cueing paradigm. By systematically varying SOA-D and the relative location between cue and target I studied the characteristics of facilitation as well as IOR. No matter whether single and double cueing was presented in intermixed or blocked trials, facilitation and IOR was found for single cueing, but not for double cueing. I speculate that the occurrence of facilitation for single cueing may be due to the temporal overlap of cues and targets between trials and blocks. The results for double cueing in Exp. 4A showed that IOR occurred at more than one location, that the most recently cued location produced the

strongest IOR, and that IOR accumulated at the same location. When single and double cueing trials were presented in separate blocks, the second cue generated facilitation for short SOA between second cue and target and produced weaker IOR for long SOA between second cue and target. These results suggest that the second cue works effectively in terms of attracting attention, which is possibly due to the expectation of observers for target onset of the second cue.

This thesis strongly supports the finding in previous research that in detection tasks facilitation is more difficult to occur whereas IOR is a robust effect (see, e.g., Collie et al., 2000; Mele et al., 2008; Tassinari et al., 1994; Tassinari & Berlucchi, 1995). This was observed when the experiment included only single and on-off cueing. Nevertheless, I found that the absence and presence of facilitation and IOR can be affected by the cue type and the number of cues. That is, for cue type, off-on cue triggered facilitation for the short SOA but eliminated IOR for the long SOA. For the number of cues, when only two cues preceded targets in a block, the second cue generated facilitation for short SOA between second cue and target and produced weaker IOR for long SOA between second cue and target, compared to when either one or two cues preceded targets in a block. The random effects of mixed models explained sufficient variance across subjects to improve estimates of facilitation and IOR and variability was mainly due to individual mean RTs (random intercepts) across conditions.

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Acknowledgement

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Thank you. You all are the sunshine of my academic journey.

Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.”

Printed Name: _________________________

Signature: _________________________

Chapter 1 Introduction

1.1 Attention

We are usually surrounded by and immersed in an environment that provides us with rich sensory information. This abundance of sensory information provides a feast for our sensory system. However, the sensory system does not act like a greedy foodie swallowing everything, but instead, like a gentle connoisseur, selectively and neatly picks up what is needed. This dynamic process of selecting sensory information is how attention works. Attention plays an important role in our daily lives, from basic daily activities such as picking up your letters from a bunch of flyers at your door, to lifesaving events like crossing the road when you see the right traffic light is green.

1.1.1 Definition of attention

> "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state…"
>
> (James, 1890, pp. 403–404)

James (1890) gave one of the first definitions of attention. Nobre (2018) interpreted this definition as indicating that, in James' perspective, attention is essentially a process (taking possession by the mind). Instead of being a type of mental representation, the word attention refers to the function which leads us to the specific contents among various options. Thus, the process of attention is in regard to prioritisation and selection, where only one item is selected at a time. This item can be an object from the external environment or from trains of thought forming an internal mental landscape. In addition, attention includes focus which involves the inhibition of (withdrawal from) irrelevant items, as well as leading to adaptive behavior (to deal effectively). Finally, attention is necessary for healthy cognition. Many new definitions of attention have been proposed after this classical definition, but they seem to share some of its underlying characteristics. For example, one concise contemporary definition was provided by Nobre and Kastner (2014) who suggested that attention is the prioritisation of processing information related to present task goals.

1.1.2 Theoretical Accounts of Attention

Different accounts of attention have been proposed. Firstly, there is the analogy of attention as a spotlight (e.g., Norman, 1968; Eriksen & Eriksen, 1974; Posner, Snyder, &

Davidson, 1980). Posner et al. (1980) described attention as being like a beam that moves across the visual field, improving the areas illuminated which results in enhanced processing of stimuli whereas worsening the segment in the dark. For example, if an item appears suddenly, this will attract the spotlight to its location with the result of a speedier detection of a stimulus in the same location, compared to the detection of a stimulus in a different location. Eriksen and Eriksen (1974) suggested that the spotlight has a fixed size of about 1° of visual angle, based on their experiment in which target letters were presented along with flanking letters as distractors. However, the spotlight account was questioned by others, who argued that instead of having a fixed size, the beam was more likely to be flexible, which led to an alternative analogy: attention acts like a zoom lens.

Eriksen and St. James (1986) raised questions about the focus of attention. In particular, they asked whether the spatial extent of the focus can change, whether processing efficiency decreases as the area of the focus increases, and whether the focus area at its boundary resembles a clear-cut edge or a spatial gradient. Their results suggest that the focus narrows with time and that a narrower beam area improves processing capability. Evidence from Shulman et al.'s (1979) and Tsal's (1983) results support the idea that the attentional focus narrows from an originally broad area to a narrower field instead of moving around like a spotlight. Castiello and Umilta (1990; 1992) also confirmed that the size of the attentional focus adapted to include stimulus areas of different sizes, that when the area of attentional focus increased the processing efficiency dropped off, and that the efficiency of processing decreased gradually around the attentional focus. In addition, other accounts of attention, for example the gradient account (LaBerge & Brown, 1989) and 'hemifield inhibition model', also called 'hemifield activation hypothesis' (Klein & McCormick, 1989), explore further characteristics.

Attention can be categorised in different ways: according to the way attention shifts, it is classified as overt or covert attention; according to how attention is elicited, it is categorised as exogenous or endogenous attention.

1.1.3 Overt and Covert Attention

While looking straight ahead, with some effort, we are able to pay attention to the periphery of our visual field at the same time (Helmholtz, 1866). That is, we can attend not only centrally but also peripherally, and we do so when we are moving our eyes. In essence, attention can be oriented overtly and covertly. On the one hand, orienting attention overtly means that the attentional spotlight is shifted to a particular region in the visual field by movement of the eyes, typically resulting in capturing the visual information with higher resolution at the fovea. Orienting attention covertly, on the other hand, means shifting the attentional spotlight without moving the eyes, capturing visual information in the extra-foveal regions of visual space. Overt orienting is often apparent, as we can usually observe eye movements during the orientation process; covert attention is more subtle, lacking saccades or having microsaccades, changing in the patterns of slight fixational eye movement, which was observed during covert visual search (e.g., Martinez-Conde et al., 2004; Martinez-Conde et al., 2013).

Making a saccadic eye movement is the most accurate and the simplest way to extract information from the visual space, because eye movements are rapid (about 300- 500 degrees of visual angle per second) and allow us to swiftly orient the segment of the retina with the highest acuity to the object we attend (Belopolsky & Theeuwes, 2012).

Although covert attention comes with reduced acuity compared to overt attention, it is more widely distributed and covers a broader scope of the environment, which is beneficial in various ways. For example, covert attention favours us when we are searching efficiently while attending accurately to fixation and at the same time attending broadly to the periphery in situations like looking for tomatoes among all sorts of vegetables, as well as monitoring our surroundings for safety reasons in situations like crossing the road while keeping an ‘eye’ on both sides to make sure that no vehicle rushes over abruptly and unexpectedly. Furthermore, you can look indirectly at somewhere of interest without fixing your eyes directly on it. For example, looking at a person without making eye contact, in a situation like when you are wondering whether that special girl is walking towards you. The advantage of covert attention in processing localised parts of the visual field in the absence of overt eye movements was illustrated by Findlay (2003). In addition, he demonstrated a number of the functional properties of covert attention.

One of the functional properties of covert attention discussed by Findlay (2003) is its ability to move from item to item on a display more quickly than overt attention. In this sense, more items would be scanned with covert attention within a given time than with overt attention alone, indicating a functional benefit for the use of covert attention. Researches have been studying the speed at which covert attention moves around a visual display. For example, Saarinen and Julesz (1991) instructed participants to report letters displayed successively around a fixation. Based on the results, which indicated that performance was above chance even with an interval as short as 33 ms between displays of the letters, they came to the conclusion that covert attention could move at a rapid speed, although Egeth and Yantis (1997) questioned whether chance performance could be calculated for these kinds of tasks. Findlay (2003) also mentioned that an often neglected problem of a model of covert attention is that the magnitude of the effects is always relatively small, with the example that spatial cueing often shows an advantage in reaction time no larger than 40 ms.

Another functional property mentioned by Findlay (2003) is that covert attention is an essential part of the active vision cycle of fixating on items of interest. That is, the fixation act in essence is paying attention with support provided by covert processes which result in previews in periphery for the next fixation location, which has been studied as early as the 1980s (e.g., Loftus, 1983; Rayner & Pollatsek, 1987). In this sense, overt and covert attention are intrinsically associated. The relation between these two types of attention has been studied for years.

The Premotor theory proposed by Rizzolatti, Riggio, Dascola and Umilta (1987) postulated that these two types of attention are controlled by the same mechanism and that covert attention occurs due to the mechanisms of eye movement preparation, although the actual movement is withheld. More specifically, the mechanism underlying covert attention is a shift of spatial attention including all the essential steps of saccade preparation, except that the actual motor execution is absent (see also Klein, 1980; Klein & Pontefract, 1994). There is also evidence from neurology in support of the view by Rizzolatti et al. (1987) that overt and covert attention are connected by a common neural architecture through a mutual frontoparietal network (Beauchamp et al., 2001; Corbetta, 1998; de Haan et al., 2008).

1.1.4 Exogenous and Endogenous Attention

William James differentiated between two kinds of attention (James, 1890): one is passive, reflexive and involuntary, whereas the other is active and voluntary. The former is now referred to as exogenous/transient attention and the latter as endogenous/sustained attention (Carrasco, 2011). There are also other labels for these. Exogenous attention is also known as ‘bottom-up’ and ‘stimulus-driven' attentional control, while endogenous is also known as ‘top-down’ and ‘goal-directed’ attentional control (Chun, Golomb & Turk-Browne, 2011). The associations between these labels are that exogenous attention, which is thought to occur automatically, generally relates to external stimuli (peripheral stimuli in particular), and thus it is considered to be a bottom-up, reflexive, and stimuli-driven control, while endogenous attention primarily relates to internal goals and intentions, and hence it is regarded as a top-down, voluntary and goal-directed selective process. An example of shopping helps to illustrate the distinction between these two types of attentional controls. Imagine that now you are in a grocery shop, looking for a tomato among various vegetables. You will voluntarily shift your attention from one vegetable to another between shelves, until the external input (i.e., what you see) matches the physical appearance of a tomato in your internal knowledge and this is when your attention is controlled by the endogenous mechanism. In contrast, while you are searching for tomatoes, a bee that suddenly and unexpectedly appears, dancing in the air around the flowers on a shelf next to you, will automatically capture your attention and this will be when your attention is driven by the exogenous control.

Experimentally, cues, stimuli showing in the visual field, were used to trigger these two types of attentional orientation. It was Posner et al. (1980) who popularised the distinction between exogenous and endogenous cueing. In general, exogenous cueing directs attention to a location by means of a cue (e.g., a flashed stimulus) which often shares the same location as targets, whereas endogenous cueing draws attention to a location via a symbolic cue which indicates where to attend (e.g., arrows, or the words ‘left’ or ‘right’), often appears in the fixation and does not share locations with targets (Hommel et al. 2001).

The shifts of attention directed by central cues appear to be under conscious control and thus observers can allocate resources based on cue validity (Giordano, McElree, & Carrasco, 2009; Mangun & Hillyard, 1990). However, attention can still shift involuntarily even when observers are aware the cues are irrelevant and uninformative (Barbot et al., 2011; Montagna, Pestilli, & Carrasco, 2009; Pestilli et al., 2007; Yeshurun & Rashal, 2010), and when responding to the cues may cause impairment of their performance (Carrasco, Loula, & Ho, 2006; Hein et al., 2006; Yeshurun, 2004; Yeshurun, Montagna, & Carrasco, 2008). In short, ignoring peripheral cues is extremely hard for observers (Giordano, McElree, & Carrasco, 2009; Yantis & Jonides, 1996). Notice that either covert or overt spatial attention can be modulated by exogenous and endogenous cues (Corbetta & Shulman, 2002). Different types of paradigms will be demonstrated later, in the section on cueing paradigms.

Exogenous and endogenous attention differ in their time courses. As mentioned, exogenous attention is also referred to as ‘transient’ attention and endogenous attention is labeled as ‘sustained’ attention. They are alternatively termed in this way due to and according to their different temporal characteristics. Endogenous attention deploys over time (i.e., it is an attention effect with a cue to be detected), taking about 300-500 ms to build up following the onset of a central cue (e.g., Müller & Rabbitt, 1989; Cheal & Lyon, 1991; Nakayama & Mackeben, 1989), but this voluntary deployment of attention can be sustained at a location for a long period (Prinzmetal et al., 2009; Wright and Richard, 2000) of at least about 1200 ms (Müller & Rabbitt, 1989). Conversely, exogenous attention builds up rapidly, taking only 90-120 ms to deploy at a given location, but its benefits are relatively short-lived compared to endogenous attention, lasting only for about 300 ms after cue onset (Müller & Rabbitt, 1989; Cheal & Lyon, 1991; Nakayama & Mackeben, 1989). Furthermore, the benefit of the involuntary deployment at the captured location shortly thereafter turns into a relative inhibition effect, which is termed ‘inhibition of return’ while the benefit is named ‘facilitation effect’, alternatively simply referred to as ‘facilitation’ (Posner and Cohen, 1984). These two effects are the main subjects of this thesis and will be illustrated in a latter section.

Taking into account the distinction in the ways of triggering these two forms of spatial attention and the differences in their phenotypes, exogenous and endogenous attention are considered to arise from different neuronal mechanisms (Carrasco, 2011; Corbetta & Shulman, 2002), and, at the same time, have a strong overlap in the brain regions (Corbetta & Shulman, 2002; Kincade et al., 2005; Peelen et al., 2004), according to evidence from studies using functional neuroimaging techniques.

A bilateral fronto-parietal network (i.e., dorsal attention network) is activated by both forms of attention, even when the attentional task requires no spatial orientation or saccadic eye movements (Coull et al., 2000). The dorsal attention network is found to be consistently activated for endogenous shifts of attention, even without cue stimuli (Hopfinger et al., 2010). An event-related potentials (ERP) study showed that when exogenous and endogenous attention were competing with one another, exogenous attention showed dominant advantages in early components whereas endogenous attention showed advantages in later components (Hopfinger & West, 2006). This is consistent with their time courses. In addition, evidence from non-human animal, human lesion and ERP studies suggests that exogenous attention is more parietally-dominated while endogenous attention appears to be more frontally-dominated (Baluch & Itti, 2011, Buschman & Miller, 2007, Li et al., 2010), which has been extended to human neuroimaging findings (Meyer, Du, Parks & Hopfinger, 2018). It is also suggested that, although these two types of attention may be based on the same neural substrates, exogenous attention may rely on parietal-to-frontal processes, whereas endogenous attention may rely on frontal-to-parietal processes (Baluch and Itti, 2011, Li et al., 2010). In short, their neural mechanisms partly overlap and interact with one another.

Previous research has been investigated the relation between covert and overt attention when they are being activated by exogenous attention or endogenous attention, respectively. A sudden onset in the visual periphery can trigger covert (Yantis & Jonides, 1984) and overt attention (Theeuwes, et al., 1998). Researchers has been studying the reason why both covert and overt attention can be induced by an abrupt onset in the visual periphery. It has been suggested that covert and overt attention are associated by a common neural architecture (e.g., Grosbach & Paus, 2002; Moore & Fallah, 2001; Perry & Zeki, 2000), or they are dissociated but being triggered by a sudden onset (Hunt & Kingstone, 2003). Moreover, Hunt and Kingstone (2003) suggested that the covert and overt attention are also independent for voluntary shifts.

1.2 The Posner Cueing Paradigm

The Posner cueing paradigm (Posner, 1980) has become seminal for studies of attention. In this paradigm, observers are instructed to respond as fast as possible to a target in the periphery, preceded by a cue, Figure 1.1. The cue can be either a transient stimulus appearing briefly in the periphery (e.g., a flashed square) or a symbolic stimulus at the centre (e.g., an arrow pointing to the left or right). These different cues have been used to study exogenous and endogenous attention, respectively. In addition, observers can be instructed either to keep their eyes fixated at the centre of the display, or to make saccadic eye movements following the cue, which allow the study of covert and overt attention accordingly. Furthermore, variants of the classic paradigm have been employed (for a review, please see Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014): the task can be a simple detection task or a discrimination task and responses can be made either manually by key-press or by eye movements.

1.2.1 Covert Orienting of Visual Attention Task (COVAT)

Among the many types of cueing paradigms, the original Posner cueing paradigm is particularly useful for measuring covert and exogenous attention, because this paradigm requires participants to keep their eyes fixated at the centre of the screen and to respond manually to a target preceded by uninformative cues and appearing in one of two peripheral locations to the left or right of fixation. Uninformative cues are cues that do not indicate where targets will appear (e.g., McAuliffe & Pratt, 2005; Colzato, Colzato, Pratt, & Hommel, 2012). This task is named the ‘covert orienting of visual attention task’, or COVAT (e.g., Maruff et al., 1999; McAuliffe & Pratt, 2005). Although such a simple paradigm is not as ecologically valid as more complex scenes, such as a display with several target locations in a circular arrangement, it has inherent advantages. Unlike a more complex or cluttered display with different colours and shapes (e.g., displays like ‘Where’s Waldo’), the COVAT is easy to manipulate and control as well as replicate. These advantages have contributed to the popularity of using COVAT when investigating the mechanism of information processing in both humans and animals. As a result, it has helped to develop and enrich our understanding of information processing during exogenous and covert orienting of visual attention.

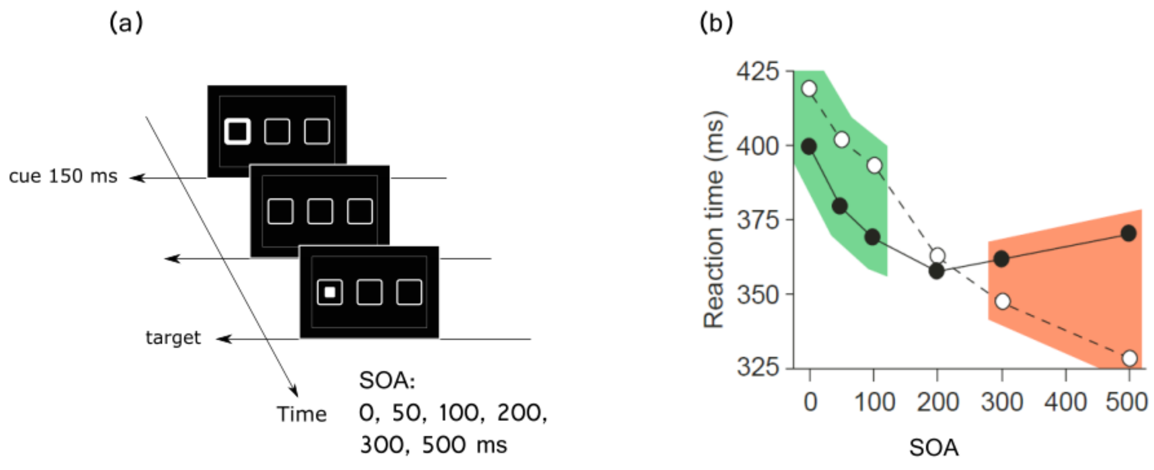


Figure 1.1. The prototypical demonstrations of (a) the classic Posner Cueing Paradigm and (b) facilitation and IOR. Figure (b) is reproduced from Klein (2000), Fig. 1, p. 139. (a) The sequence of events in a trial of the classic paradigm. At the start of a trial, a fixation display is presented including three frames which appear as placeholders for cues and targets. One peripheral box will then be brightened as a cue (S1). After varying intervals (SOA), a target (S2) appears. A valid condition is when the targets appear at the same location as the cues, whereas an invalid condition is when the targets appear at a different location from the cues. Normally, cues and targets appear in the periphery. However, in some studies targets will appear at the central location to return attention from the periphery to the centre. In addition, catch trials including cues but no targets are set to discourage anticipatory responses. It is also a prototypical demonstration of Covert Orienting of Visual Attention Task (COVAT). (b) The results from an experiment using such paradigm (Posner & Cohen, 1984). Responses to valid trials are indicated as filled circles, whereas invalid trials as open circles. Faster responses to targets appearing at the cue location compared to the horizontally opposite location with short intervals (green) reflects a facilitation effect, whereas slower responses to targets appearing at the cue location compared to the horizontally opposite location with long intervals (red) reflects IOR.

1.2.2 Facilitation and IOR

In the Posner cueing paradigm, cues can bring both benefit and cost to responses to targets. To illustrate, consider, for example, a simple detection task with uninformative and peripheral cues (i.e., COVAT). The benefit is that, in the condition of a short time interval between cues and targets, responses are faster when the targets appear at the same location as the cues relative to when the targets appear at a different location. However, with a longer interval, the result reverses, with a slower response when the target appears at the cue location compared to the location not preceded by a cue, which is the cost of cues. The benefit has been labeled the ‘facilitation’ effect (Posner & Cohen, 1984) and the cost ‘inhibition of return’, or IOR (Posner, Rafal, Choate, & Vaughan, 1985). The interval between cue onset and target onset is generally referred to as the stimulus-onset-asynchrony (SOA). The crossover point, where facilitation is replaced by inhibition, occurs between 200 ms and 300 ms after cue onset (Posner & Cohen, 1984; for a review, see Collie, Maruff, Yucel, Danckert, & Currie, 2000). These two effects, one positive and one negative, i.e., facilitation and the inhibition following it, are labelled the biphasic effect of non-informative peripheral spatial cues (e.g., Tassinari & Berlucchi, 1995; Pratt & Hirshhorn, 2003), see Figure 1.1.

In different variants of the original Posner cueing paradigm, the time courses and magnitudes of facilitation and IOR are not consistent, which largely depend on task demands (see Klein, 2000, for a review). For example, compared to detection tasks, in discrimination tasks the crossover point where facilitation turns into inhibition becomes slower; that is, the benefit of cueing disappears at a longer time interval after the cue onset and the appearing of cost is delayed (e.g., Lupiáñez et al., 1997). In contrast, IOR occurs earlier when responses are made with saccades rather than manually (e.g., Briand et al., 2000). According to Klein (2000), one possible reason that can account for the differences of crossover points in different tasks is attentional control setting. He explained that, when a trial starts, observers internally allocate a level of attention to a target according to the demands of the task: low intensity for simple detection tasks and high intensity for difficult discrimination tasks. An uninformative peripheral cue should not receive the same level of attention as targets, but, in fact, it does. This is because changing the attentional control setting requires time, just as task switching does, so that the control setting chosen to process targets is already in place before the onset of cues. As a consequence, the higher the intensity of attention selected for targets, the more attention the cue will receive. If the attention allocated to cues is more intensive, attention will dwell on cues for longer. This will increase the facilitation effect and delay or even eliminate the appearance of IOR.

The mechanisms of facilitation and IOR, as well as their relationship, have been popular questions leading to an impressive amount of research covering many different topics in the field of attention and cognitive neuroscience. The paper by Posner and Cohen (1984) has been cited more than 1,800 times by papers in the Web of Science Core Collection. Table 1.1 (data from Web of Science Core Collection) lists the top 12 research papers, excluding review papers, that were cited by the top 500 papers citing the original paper by Posner and Cohen (1984). The citation relation between these 12 papers is shown in Figure 1.2, created by HistCited (Version 12.3.17, 2018), a software for bibliometric analysis and information visualisation. These 12 papers discussed hypothetical mechanisms of facilitation and IOR (e.g., neural basis, time courses, causes) and investigated various factors extending the classic paradigm (e.g., task types, response types), which explored different aspects of these popular and fascinating questions.

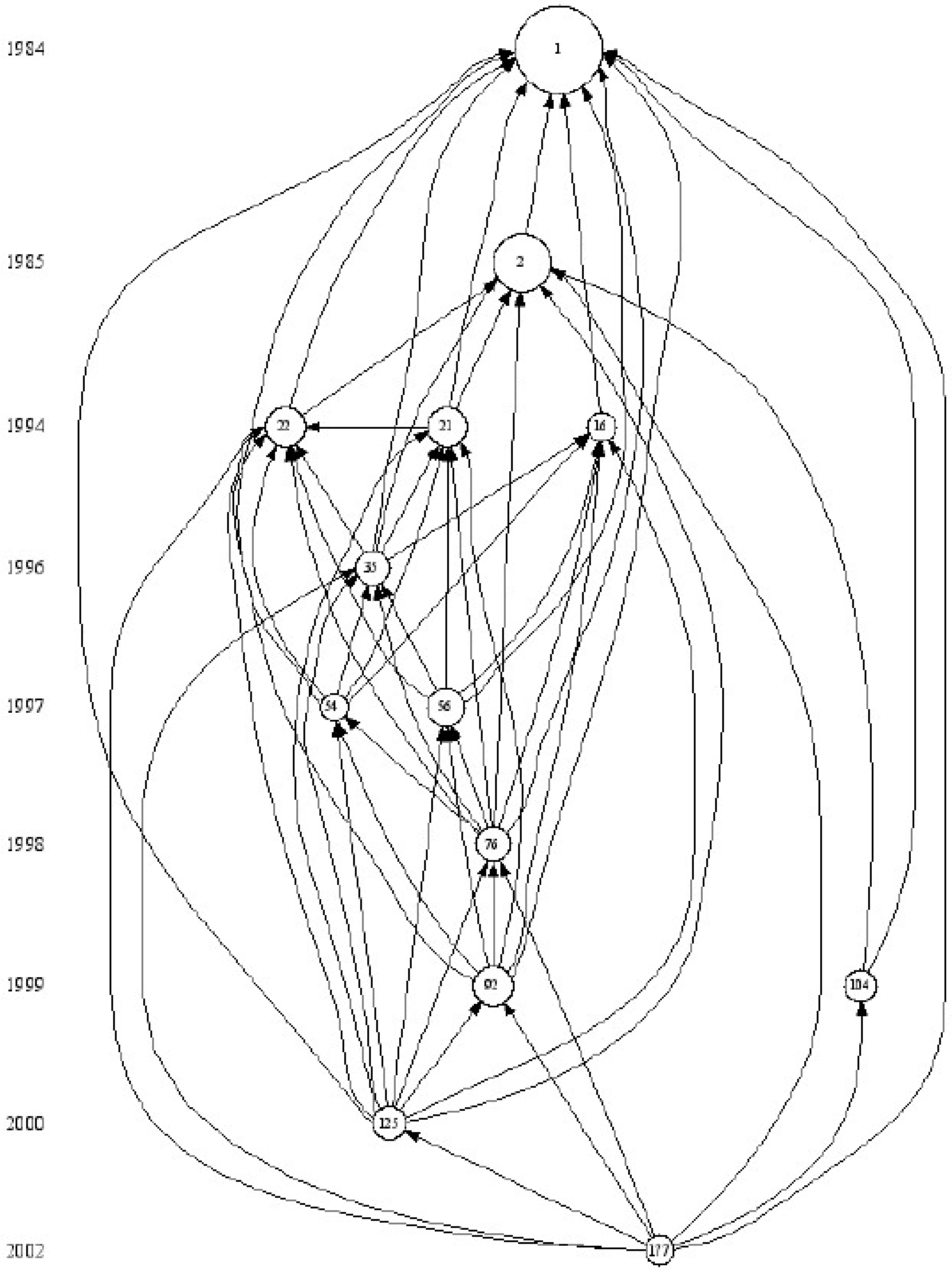
Table 1.1

List of the top 12 research papers, excluding review papers, cited by the top 500 papers that follow up on the original paper by Posner and Cohen (1984)

No.	*Authors*	*Title*	*Year*	*LCS*	*GCS*
1	Posner, Cohen	Components of visual orienting	1984	500	1810
2	Posner, Rafal, Choate, Vaughan	Inhibition of return - neural basis and function	1985	226	738
16	Terry, Valdes, Neill	Does inhibition of return occur in discrimination tasks	1994	61	100
21	Abrams, Dobkin	Inhibition of return - effects of attentional cueing on	1994	109	205
22	Tipper, Weaver, Herreat, Burak	Object-based and environment-based inhibition of return of visual-attention	1994	108	255
35	Reuter-Lorenz, Jha, Rosenquist	What is inhibited in inhibition of return?	1996	87	152
54	Pratt, Kingstone, Khoe	Inhibition of return in location- and identity-based choice decision tasks	1997	59	96
56	Lupianez, Milan, Tornay, Madrid, Tudela	Does IOR occur in discrimination tasks? Yes, it does, but later	1997	100	252
76	Taylor, Klein	On the causes and effects of inhibition of return	1998	87	211
92	Klein, MacInnes	Inhibition of return is a foraging facilitator in visual search	1999	107	376
104	Sapir, Soroker, Berger, Henik	Inhibition of return in spatial attention: direct evidence for collicular generation	1999	69	202
125	Taylor, Klein	Visual and motor effects in inhibition of return	2000	77	196
177	Dorris, Klein, Everling, Munoz	Contribution of the primate superior colliculus to inhibition of return	2002	61	185

Note. The citation relations between these 12 papers are shown in Figure 1.2. These 12 papers include hypothetical mechanisms of facilitation and inhibition and investigation of various factors on the classic paradigm. Interpretation of glossaries: the Local Citation Score (LCS) shows the count of citations to a paper within the top 500 papers; the Global Citation

Score (GCS) shows the total number of citations to a paper in the Web of Science Core Collection; LCS is considered to be important, because it measures how often a paper has been cited in the field of this topic.



Nodes: 13, Links: 57
13 marks; Min: 59, Max: 500 (LCS scaled)

Figure 1.2. The citation relations between the 12 papers in Table 1.1. These are the top 12 research papers (i.e., excluding review papers) cited by the top 500 papers citing the original paper by Posner and Cohen (1984). This figure was created by HistCited (v12.3.17, 2018), a software for bibliometric analysis and information visualisation. The size of the nodes represents the number of times a paper has been cited by the top 500 papers published after it (see LCS in Table 1.1). In other words, the bigger the node, the more this paper has been cited in the field of this specific topic, i.e., the size of the node indicates how important this paper is in this field. When importing the top 500 papers, a number (from 1 to 500) is attached to each paper in order of the publication time by default. The number for each paper is shown on its node.

1.2.3 Neuropsychology and Brain Defects

IOR has been used to investigate different issues in cognitive neuroscience, especially in the fields of attention and spatial cognition. It is a tool used to investigate the underlying mechanisms as well as the corresponding neural structures.

It has long been suggested that the superior colliculus is an important structure for IOR (e.g., Dorris, Klein, Everling, & Munoz, 2002; Ignashchenkova, Dicke, Haarmeier, & Thier, 2004; Sapir, Soroker, Berger, & Henik, 1999). Evidence has shown that most of the single neurons in the intermediate layers of the superior colliculus both responded to visual stimuli and had saccade-related activity (Bell, Fecteau, & Munoz, 2004). In a classic paradigm, monkeys made faster saccades to targets in cue locations than to targets in an opposite location not preceded by cues with a short SOA, which indicated facilitation effects. However, with a long SOA, the saccade responses reversed, which means IOR appeared. Visual-motor neurons in the superior colliculus showed responses to cues and targets appearing in the receptive field and the activity of these neurons paralleled the behavioural results. With short SOAs, the combined response to cues and targets at the same location was greater than responses to targets at a location opposite to cues. However, with long SOAs, the responses of neurons to targets preceded by cues were smaller compared to the responses to targets opposite the cue location.

In addition, IOR has been used to investigate the development of the mechanism of attentional orientation from newborns to the elderly, as well as to study attention in patients with psychological, psychiatric, and neuropsychological disorders. Although many studies with Alzheimer’s disease patients have observed a relatively typical IOR (Danckert, Maruff, Crowe, & Currie, 1998; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001; for a review, see Amieva, Phillips, Della Sala, & Henry, 2004), IOR effects with deficits were observed when some parameters of the procedure, such as time course (Langley et al., 2001), the task (Langley et al., 2001), or the presentation of central reorienting cues (Faust & Balota, 1997) were manipulated. In addition, reduced or even eliminated IOR effects were observed in studies with Parkinson’s disease patients (Poliakoff, O’Boyle, Moore, McGlone, Cody, & Spence, 2003). What’s more, patients with obsessive-compulsive disorder showed a reduction of IOR (Nelson, Early, & Haller, 1993; Rankins, Bradshaw, Moss, & Georgiou-Karistianis, 2004), and children and adolescents with spina bifida meningomyelocele have been observed to have attenuated IOR in the vertical plane (Dennis et al., 2005). As for schizophrenic patients, when compared to control participants, Gouzoulis-Mayfrank et al. (2004) observed blunted IOR, and Larrison-Faucher, Briand, and Sereno (2002) observed delayed onset of IOR, whereas Fuentes and colleagues have observed normal IOR in medicated schizophrenic patients (Fuentes, Boucart, Alvarez, Vivas, & Zimmerman, 1999; Fuentes & Santiago, 1999). Also, it has been suggested that the absence versus presence of a central reorienting cue at fixation affected the presentation of IOR in medicated patients (Sapir, Henik, Dobrusin, & Hochman, 2001).

1.2.4 Theoretical Accounts of Facilitation and IOR

Several accounts have been proposed in order to explain facilitation and inhibition in the Posner paradigm, including the attentional account, sensory account, motor bias account, etc.

1.2.4.1 The Attentional Account

The attentional account refers to the classic explanation of facilitation and inhibition as biphasic effects (Posner & Cohen, 1984; Rafal & Henik, 1994). According to this account, attention is attracted by peripheral cues and shifts reflexively to the cue location (Posner & Cohen, 1984). This leads to a benefit for responding to targets appearing shortly after cue onset at the cue location compared to locations that are not preceded by cues. That is when researchers observed facilitation with short SOAs. Following this idea, the late inhibition effect, IOR, has been interpreted as inhibition from returning to previous cued locations (Posner, Rafal, Choate, & Vaughan, 1985).

However, this account was not supported by previous studies (e.g., Prime et al., 2006; Riggio, Bello, & Umiltà, 1998). For example, evidence from temporal order judgment tasks, in which participants were asked which of two targets appeared first (Posner et al., 1985), showed that targets at cue locations were perceived as appearing earlier than targets at locations which were not preceded by cues. If attention shifts away and is biased against the cue location, as described by the attentional account, the result should be the opposite; that is, the targets at cue locations should be perceived as appearing relatively later. In addition, although, as implied by the label ‘the biphasic effect’, both facilitation and inhibition effects were observed in many studies (e.g., Bayliss, di Pellegrino, & Tipper, 2005; Lambert &

Hockey, 1991; Rafal & Henik, 1994), in some cases, IOR and facilitation did not always appear. Facilitation, especially, often did not appear. Unlike robust inhibition, facilitation was not always found (e.g., Chen, Moore, & Mordkoff, 2008; Tassinari & Berlucchi, 1995), and only IOR was observed instead.

Based on these contrasting pieces of evidence, researchers put forward new proposals regarding the relationship between facilitation and IOR. Instead of a biphasic effect, facilitation and IOR were considered to be separable and independent processes. These proposals were accompanied by alternative theories, such as sensory and perceptual merging accounts of facilitation, as well as motor bias and foraging accounts of inhibition.

1.2.4.2 The Sensory Account

An energy summation account has been proposed as an alternative theoretical framework for the facilitation effect. It is said that cues could have low-level sensory effects and sensory advantages, i.e., facilitation could be the result of bottom-up changes, induced by cues, in the properties of cells in the visual system (Krüger, MacInnes, & Hunt, 2014). How do bottom-up changes caused by cues confer facilitation? The answer could be found from previous work on the summation of light energy. Facilitation with short SOAs occurs due to the summation of light energy between cues and targets when they temporally overlap; that is, targets appear before cue offset (Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). This sensory account has been used for describing IOR as well. Posner and Cohen (1984) conducted an experiment including single cueing and double cueing, in which two cues appeared simultaneously. IOR induced by double cueing was as strong as the single cueing, but no facilitation was observed in the double cue trials. Based on these results and evidence from a following arrow experiment, they suggested that inhibition is not induced by attentional orientation, but from energy changes at the cue location.

1.2.4.3 The Motor Bias Account

It has been suggested that inhibition occurs due to the requirement of COVAT that participants need to maintain their fixation at the centre of the screen (Collie, Maruff, Yucel, Danckert, & Currie, 2000). Maintaining fixation at the central location inhibits intended saccades initiated by peripheral cues. As a result, the motor system is biased against making responses to targets appearing at locations preceded by cues. In other words, the motor hypothesis of IOR contains two parts: The inhibition of saccades towards cue locations, and the response bias against cue locations.

The work from the studies by Posner et al. (1985) requiring saccadic responses seconded the idea of the inhibition of saccades towards cue locations. They presented two targets in rapid succession, following a peripheral cue and a central cue to return to the fixation, with one target at the cue location and the other one at another location. Participants were asked to make saccades to the ‘more comfortable’ location of the two. It turned out that participants tended to make saccades away from the locations preceded by cues. In addition, Rafal et al. (1989) conducted studies requiring manual responses and found that, for exogenous cueing (peripheral luminance changes), cue locations were inhibited when no saccades were included (attended cue locations covertly), when preparation of saccades was made (these saccades were cancelled by a central cue), and when saccades were made (attended cue locations overtly).

The idea of response bias against cue locations was extended by the target-target studies by Maylor and Hockey (1985), in which cues were removed as well as the hypothesised response bias against locations induced by cues. Participants responded to targets between which there were different time intervals. However, in such cases in which no response inhibition to stimuli was included, IOR still appeared at the locations preceded by a previous target. It appears that, whether or not responses were encouraged to make to a stimulus, the location it precedes is inhibited. In other words, it seems that inhibitory tags (Klein, 2000) attached to locations can be left not only by cues, but also by stimuli which are not encouraging responses.

1.2.4.4 Miscellaneous Accounts for the Facilitation and IOR

Other accounts are suggested for facilitation and IOR separately. For example, for facilitation, Krüger, MacInnes, and Hunt (2014) put forward a theory that the facilitation of peripheral cues is due to cue-target perceptual merging because of re-entrant visual processing. This theory is inspired by the idea that when two peripheral events (cues and targets) appear at the same location, they are more likely to be perceived as one event (Bouvier & Treisman, 2010; Enns & Di Lollo, 2000; Lamme & Roelfsema, 2000; Lamme, Zipser, & Spekreijse, 2002; Treisman, 1996). Other accounts for IOR have also been proposed, and are introduced as follows.

There is a foraging account by Klein (1988) which proposes that the reason for IOR biases against recently inspected locations is that IOR could function as a foraging facilitator; in other words, IOR facilitates visual search. This is supported by evidence from studies using parallel and serial search (Klein, 1988) as well as studies of visual search using more complex scenes from the *Where’s Waldo?* series of books (Klein & Maclnnes, 1999).

Dukewich’s (2009) habituation account conceptualised IOR as habituation of the orienting response (Sokolov, 1960, 1963). From this perspective, identical stimuli appearing successively at the same location would induce the most robust habituation. In contrast, a target with a different appearance from the preceding stimulus would hypothetically benefit from dishabituation.

Lupiáñez (2010) put forward a three-component framework to illustrate the time course of benefits and costs following an uninformative peripheral cue in detection and discrimination tasks. The core of this framework is a sophisticated model including the following three components: Spatial selection benefit, spatial orienting benefit, and onset detection cost. The first two components bring benefits to performance, whereas the last one cost impairment.

1.2.5 Temporal and Spatial Factors

The mechanisms of facilitation and IOR, as well as their relationship, has been a popular question leading to an impressive amount of research in cognitive neuroscience and the field of attention. To study this question, researchers have manipulated different factors ranging from paradigms (e.g., item features, task difficulties, object movement, cross modals) to individual differences (e.g., age, gender, brain deficits and lesions). As more factors were added, more aspects of the question were revealed to be discussed, from hypothetical computational models to neural bases. Similar to pieces in a jigsaw puzzle, these factors, which kept updating parts and pieces of our knowledge, contributed toward revealing the picture of this question. It should be noticed that, among all these factors, there are two which, although basic, were two of the earliest pieces of this jigsaw puzzle, because they are so fundamental to all the relevant paradigms. These two are the temporal and spatial factors, more specifically, the temporal and spatial relations between cues and targets.

1.2.5.1 Why are temporal and spatial factors fundamental?

To investigate both facilitation and inhibition, two factors are essential in a paradigm: Stimuli Onset Asynchrony (SOA) and Validity.

SOA is commonly referred to as the time difference between the cue onset and the target onset. As mentioned earlier, facilitation occurs when targets are shown briefly after the cue onset (i.e., when there are short SOAs) while IOR occurs when targets are presented after a long interval following the cue onset (i.e., when there are long SOAs). Researchers have manipulated SOAs in order to study facilitation and IOR. In essence, SOA is a temporal factor.

As for the spatial factor, in paradigms using COVAT, Validity means the spatial difference between peripheral cues and targets. To test whether there are facilitation and IOR effects, researchers compare simple reaction times to targets appearing at the cue location (valid conditions) with reaction times to targets at locations not preceded by cues (invalid conditions). Valid and invalid conditions are sometimes labelled as cued and uncued. However, the term ‘uncued’ is ambiguous as it can also refer to trials where no cue appeared. For this reason, in this thesis I use ‘valid’/‘invalid’ to refer to the levels of factor Validity. In paradigms using COVAT, where stimuli appear in the periphery, are more related to exogenous attention, whereas in paradigms investigating endogenous attention, central cues (e.g. arrows) are used instead. Taking arrow cues as an example, Validity refers to whether targets appear at the location in the direction pointed by arrows; ‘yes’ is valid and ‘no’ is invalid.

In short, the spatial factor, Validity, is needed when studying facilitation or IOR while the temporal factor, SOA, is necessary when looking into both facilitation and IOR in a single paradigm. Therefore, to study the mechanism underlying facilitation and inhibition as well as their relationship, the roles of temporal and spatial factors are as important as they are fundamental.

1.2.5.2 Manipulation of the Temporal and Spatial Factors

The temporal relationship between cues and targets as a temporal factor in COVAT involves not only SOA, but also other aspects, one of which is whether there are temporal overlaps between cues and targets (e.g., Maruff, Yucel, Danckert, Stuart, & Currie, 1999; McAuliffe & Pratt, 2005). Similarly, the spatial relationship between cues and targets as a spatial factor in COVAT involves not only the location differences between cues and targets (i.e., validity), but also whether cues and targets overlap spatially (e.g., McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001).

1.2.5.3 Temporal Overlap

By manipulating the duration of cues and targets, as well as the SOA, the factor of temporal overlap can be classified into three forms according to how long cues appear during the target duration: complete, partial, or no temporal overlap. More specifically, complete temporal overlap is when cues appear throughout the target duration (e.g., Berger, Dori, & Henik, 1999; Collie, Maruff, Yucel, Danckert, & Currie, 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). Partial overlap is when cues appear before the target onset, but disappear before the target offset (e.g., Berger, Dori, & Henik, 1999; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). No overlap is when cues disappear before the target onset (e.g., Berger, Dori, & Henik, 1999; Bayliss, di Pellegrino, & Tipper, 2005; Pratt, Hillis, & Gold, 2001, Posner & Cohen, 1984).

1.2.5.4 Spatial Overlap

The factor of spatial overlap discussed here is defined by how many areas one covers another with the premise that when cues and targets appear in the same spatial position, i.e., valid conditions. The word ‘positions’ here means the potential locations of cues or targets. The reason for this premise is that it is meaningless to talk about spatial overlaps when the cues and targets are in different positions (invalid conditions), which are obviously non-overlapping.

Notice that the factor of spatial overlap does not take temporal factors into account. To clarify, imagine a situation in which cues and targets are in the same shape, say, two circles of the same size. When a target appears at the cue location, where the cue remains, it is obvious that the cue and the target are spatially overlapping. If we make changes to this situation so that the cue disappears before the target onset, the target is now no longer covering or on top of the cue for the time being. In this new situation, the cue and target are still counted as spatially overlapping. In other words, spatial overlap is more about tags or prints in specific spatial positions in memories.

The factor of spatial overlap between cues and targets can be categorized into three forms according to the areas they share: complete, partial, and no spatial overlap. Complete spatial overlap is typically when cues and targets are the same shape as well as the same size; that is, the area they share is equal to the area of items, for example, when cue and target are both an asterisk (e.g., Pratt & Abrams, 1995), or squares with the same pattern (e.g., McAuliffe & Pratt, 2005; Pratt, Hillis, and Gold, 2001), or shown by the same light emitting diodes (LEDs) but indicated by different colours (e.g., Tassinari & Berlucchi, 1993, 1995; Tassinari et al. 1989). No spatial overlap is when cues and targets share an area equal to zero, which is prevalent in COVAT, in which cues are normally thick frames and targets are smaller squares (e.g., Posner & Cohen, 1984; Bayliss, di Pellegrino, & Tipper, 2005). Partial spatial overlap is the situation in between, when the area shared by cues and targets is less than the area of the smaller item but larger than zero when they are different sizes, or less than the area of the item when they are the same size, for example, when the cues are filled circles smaller than filed square targets (McAuliffe & Pratt, 2005).

1.2.5.5 The Factors of Temporal and Spatial Overlap on Facilitation and IOR

Although the factor of temporal overlap can be classified into three forms, which are complete, partial, and no temporal overlap, the question of how facilitation and inhibition will be affected when there is temporal overlap or not is more of interest. In other words, the condition of no temporal overlap is generally compared with temporal overlap, which includes both complete and partial temporal overlaps.

Studies investigating the factor of temporal overlap have shown that facilitation occurred only when the SOA was short and there was temporal overlap between cue and target (Collie, Maruff, Yucel, Danckert, & Currie, 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). However, the evidence also showed that the occurrence of facilitation was irrelevant to the temporal overlap between cues and targets (Berger, Dori, & Henik, 1999; McAuliffe & Pratt, 2005). In addition, Tassinari et al. (1994) did not observe facilitation in all four experiments in which cues temporally overlapped targets. However, they argued that facilitation could be inferred indirectly from weaker inhibition, with the speculation that facilitation might occur at the same time as inhibition instead of preceding inhibition.

The effects of temporal overlap on inhibition are more consistent. In contrast to facilitation, inhibition was present only when the SOA was long and there was no temporal overlap between cue and target (Collie, Maruff, Yucel, Danckert, & Currie, 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). Similarly, Tassinari et al. (1994) observed no inhibition when cues stayed on during target presentation and after target offset; that is, when cues temporally overlapped targets. In addition, McAuliffe and Pratt (2005) found that inhibition occurred only when there was a time interval between cue offset and target onset (i.e., cues did not temporally overlap targets) if cues spatially overlapped targets.

The biphasic effect, in which early facilitation is followed by inhibition, occurred when there was a temporal overlap between cue and target with a short, but not a long, SOA (Maruff, Yucel, Danckert, Stuart, & Currie, 1999).

For effects of the factor of spatial overlap on facilitation and IOR, facilitation was found only when there were non-overlapping cues (McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001). However, IOR effects occurred with all types of cues, complete, partial, and no spatial overlapping cues (Pratt, Hillis, & Gold, 2001). In addition, McAuliffe and Pratt (2005) compared the conditions of complete and no spatial overlap. They found that the time interval between cue offset and target onset had fewer effects on IOR effects when cues spatially overlapped with targets, as in this condition inhibition effects mostly occurred compared to the condition cues not spatially overlapping targets. In other words, inhibition effects tended to occur when there is spatial overlap between cues and targets.

1.3 Aims of the Current Thesis

Previous researches has reported that the magnitude of facilitation and IOR was affected by physical characteristics of cue (e.g., Lambert & Hockey, 1991; Pratt, Hillis, & Gold, 2001) and target (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996) on the COVAT. For example, Lambert and Hockey (1991) in their experiment 3 found that when cue had a low perceptual salience, facilitation for the SOA 100 ms were significantly greater than the facilitation for cues of a high perceptual salience. In addition, Reuter-Lorenz, Jha, and Rosenquist (1996) found that IOR was significantly greater for low rather than high luminance targets. This thesis will examine both facilitation and IOR and how they are affected by different types of stimuli, taking into account a variety of appearances of items. More specifically, in a COVAT paradigm, which we use as the basic paradigm, although there are always cues and targets, these stimuli will be varied in different ways, similarly to circumstances in daily life. For example, a traffic light can look different in size and shape depending on the distance and viewing angle of the observer, different in colour depending on the lighting conditions and whether you wear sunglasses or not, etc. In this thesis, the parameters of stimuli will be manipulated in order to further investigate the mechanisms of facilitation and IOR, as well as their relationship. Experiments 1 to 3 investigate the effects of the physical characteristics of stimuli on facilitation and IOR, and Experiment 4 investigates how the magnitudes of facilitation and IOR are affected by double cues.

A second goal is to study individual variability in the Posner paradigm by using Generalized Linear Mixed Models (GLMMs). GLMMs reveal how much of the variability is due to individual variability in response times.

I conducted conventional ANOVAs on mean RTs as in previous studies (e.g., Bayliss, di Pellegrino, & Tipper, 2005; Colzato, Colzato, Pratt, & Hommel, 2012). Statistical testing in an ANOVA requires that data are normally distributed across conditions. However, if the distributions of raw RTs are skewed, assumption of normality will be violated. One solution is to log-transform the data before entering them into an ANOVA because skewed data after log-transformation might provide a better approximation of a normal distribution. However, the non-linear log transformation makes it difficult to interpret interaction effects.

Therefore, for skewed distribution of RTs, conventional ANOVAs may not be the most suitable option for data analyses. Generalized Linear Mixed Models (GLMMs) offer more flexibility by providing a number of advantages. Firstly, I can specify distributions that are different from a Gaussian (or log-transformed) distribution, in order to fit skewed RT data. Secondly, I can use single-trial data rather than averaged data so that all the information (e.g., individual variability) in the raw data can be exploited.

This leads to the third advantage of GLMMs, that is, explaining variability due to by-subject or by-item random effects. GLMM is an extension of Linear Mixed Effect Models that establishes not only fixed effects but also tailored random effects. Random effects can capture variability that is missed in a conventional ANOVA. For example, individual intercepts and slopes are typical random effects that can be modelled in experimental studies (e.g., Baayen, Davidson, & Bates, 2008; Baayen & Milin, 2010). Random effects may not only reduce noise and identify sources of variability (e.g., across items, participants) but may also improve estimation of fixed effects. Lastly, GLMMs can handle data transformations (link functions), unbalanced designs (i.e., unbalanced observations), and missing data.

In the analysis for all the experiments, I used R (R Core Team, 2017) and the *lme4* package (Bates et al., 2015) to model and estimate fixed and random effects in the analyses. Analyses were conducted on RT data for each trial. Analyses of RTs were fitted by Gamma distributions (setting the argument of *family* in the function *glmer()*). The gamma-link function helps to model skewed RT data. Instead of using the contrast matrix generated by the default contrast function i.e., contr.treatment(), for investigating simple effects and interactions, I used the contrast matrix defined by the function contr.sum() for deviation coding, which investigates main effects and interactions. The deviation coding (or ‘effect coding’) system compares the mean of the dependent variable for one level to the overall mean of the dependent variable.

Previous studies investigated the effect of a factor by model comparison between two models (Baayen, Davidson, & Bates, 2008; Baayen & Milin, 2010). For example, a Model A, which includes a factor A, is compared to a Model B, which is identical to Model A with the only differences that factor A is excluded from the model. However, in this thesis, in order to have an overview of data analysis, for simplicity I used *Anova()* instead. *Anova()*, from the *car* package (Fox & Weisberg, 2016), approximately tests effects for statistical significance (*p* value) and calculates analysis-of-variance tables for the fixed-effect factors and their interaction for the fitted model. In addition, the contrasts of interest for main effects and the interaction were examined by Chi-square Statistics (*p*-value adjustment method: Bonferroni) using *testInteractions()*, from the *phia* package (De Rosario-Martinez, 2015). Moreover, I used the function *lsmeans()* from the *lsmeans* package (Lenth, 2016) to perform pairwise comparisons.

In terms of statistical analysis, except for ANOVA and GLMM, I also used Bayes factors to supplement evidences from conventional hypotheses testing using p-values. Bayes factors can provide additional information, because the Bayes factor can show how strong the evidence is given from the observed data for the presence or absence of an effect (for the alternative hypothesis, denoted as BF_{10}, or for the null hypothesis, BF_{01}). Occasionally, I used Bayes factors if the evidence for the null hypothesis was of interest and *p*-values did not reach significance level. I used the *BayesFactor* package (Morey & Rouder, 2018) and the function *ttestBF()* from this package, with the argument of *paired* set to *TRUE*. I used an interpretation of the Bayes factors as suggested by Jeffreys (1961), to describe how strong the evidence is for or against the null or alternative hypotheses, see Table 1.2. For example, if the value of BF01 is 2, it means that the null hypothesis was about 2 times stronger than the alternative hypothesis.

Table 1.2

Interpretation of Bayes Factors as Evidence for Alternative Hypotheses by Jeffreys (1961)

Statistic		*Support for H_0*
Bayes Factor (BF_{01})	Inverse of Bayes Factor (BF_{10})	
1-3	1-.33	Anecdotal
3-10	.33-.10	Substantial
10-20	.10-.05	Strong
20-30	.05-.03	Strong
30-100	.03-.01	Very Strong
100-150	.01-.0067	Decisive
>150	<.0067	Decisive

Chapter 2 Cue-target Discriminability

2.1 Introduction

A visual cue in the visual periphery can influence the detection or discrimination of a visual stimulus presented afterwards. Posner and Cohen (1984) used a peripheral exogenous cueing paradigm to investigate the orientation of attention, and found a biphasic pattern in response times. This pattern depends on the time interval between cues and targets (stimulus onset asynchrony or SOA). For short time intervals (a SOA of less than 200 ms) people respond faster to targets appearing at locations preceded by cues than locations not preceded by cues, whereas this effect reverses with a long time interval (SOA greater than 300 ms). Posner and Cohen (1984) provided an account of attentional orientation suggesting that the early facilitation effect was caused by a covert shift of attention to the cue location. Posner, Rafal, Choate, & Vaughan (1985) proposed that the later inhibition effect may be due to the fact that attention is inhibited, preventing a return to the cue location. Based on this speculation, the later inhibition effects are known as Inhibition of Return (IOR). The attentional account for facilitation and IOR received both approval and disapproval. Arguments in favour of the attentional account arose because IOR can be observed without facilitation (e.g., Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1993). If, as proposed by the attentional account, IOR is due to an inhibition of attention at the previous attended location, responses to targets at the cue location with a short SOA would reflect an advantage of these locations over all other possible locations. Results showing IOR without facilitation suggest that IOR might not be the result of orienting attention.

While alternative theories for these two effects have been put forward, researchers also attempted to explain why facilitation did not precede IOR in studies such as those conducted by Tassinari et al. (1994). The studies by Tassinari et al. (1994) are intriguing because they failed to find any facilitation even after attempts to systematically manipulate the temporal relation between cues and targets, including the cue duration and SOA. By the systematic manipulation of this temporal relation, the cue and target could have a temporal overlap or no temporal overlap. Although a temporal overlap between cues and targets is not necessary for the observation of facilitation, because facilitation has been found without temporal overlap (e.g., Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Pratt & Abrams, 1995), temporal overlap can help facilitation (e.g., Collie, Maruff, Yucel, Danckert, & Currie, 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). In the studies by Tassinari et al. (1994), all four experiments included conditions with temporal overlap between cues and targets by manipulating the durations of the cues. Surprisingly, none of these experiments showed facilitation for short SOAs (0, 65, and 130 ms) and, instead, inhibition was observed for short SOAs.

Among the follow-up studies that tried to explain why Tassinari et al. (1994) failed to observe facilitation, Lupiáñez and Weaver (1998) provided an explanation that attributed the reason to the discriminability between cues and targets. They speculated that when cues and targets were shown at the same time (SOA = 0 ms), it was more difficult for participants to respond to targets that appeared at the same location (a valid condition) than to targets that appeared at the other location (an invalid condition) because of the inclusion of catch trials in their experiments. Catch trials are trials that have cues, but no targets, in order to prevent participants from anticipating target presentations. When a cue appears at a different location than the target in an invalid condition, participants immediately know that a target has appeared if there are changes at two locations. However, when there are changes at only one location, then there are two possibilities: This was either a valid trial or a catch trial, depending on whether a target appeared along with the cue. Therefore, unlike in invalid trials, it takes participants more effort to confirm that a target did appear when there are changes at only one location. This extra effort takes additional time, and hence there is a delayed response to targets in valid conditions compared to invalid conditions. As a consequence, cueing did not bring about a facilitatory effect as expected, but instead slowed processing down, resulting in no facilitation and even ‘inhibition’ in the studies by Tassinari et al. (1994).

However, if discriminability between cues and targets is easier, it will take less effort for participants to confirm the presentation of targets, and the beneficial effects of cueing should be more obvious. Pratt, Hillis and Gold (2001) designed an experiment to examine the role of discriminability between cues and targets in facilitation and inhibition. In their experiment, they manipulated cue-target discriminability by introducing differences in shape, colour, and luminance, as well as in spatial overlap. The target stimulus remained the same, a white square, whereas there were three types of cues: In the *same condition*, the cue was identical to the target; in the *different condition*, the cue was a green filled circle of a different brightness to the target, that is, the cue had a different shape, colour, and luminance to the target; in the *non-overlap condition*, the cue was the outline of a square with the same colour and luminance as the target, but without any spatial overlap (see Figure 2.1). Pratt, Hillis and Gold (2001) observed IOR in all three conditions with long SOAs, but only found facilitation in the condition with non-overlapping cues and short SOAs (100 ms and 200 ms).

Therefore, they suggested that the physical characteristics of cues and targets influence the pattern of reaction times with short SOAs, but not with long SOAs. Although Tassinari et al. (1998) disproved the hypothesis of difficult discriminability by Lupiáñez and Weaver (1998) by providing evidence that in a paradigm without catch trials early inhibition can still be observed, Pratt, Hillis and Gold (2001) supported the idea that the factor cue-target discriminability does indeed affect the facilitation.

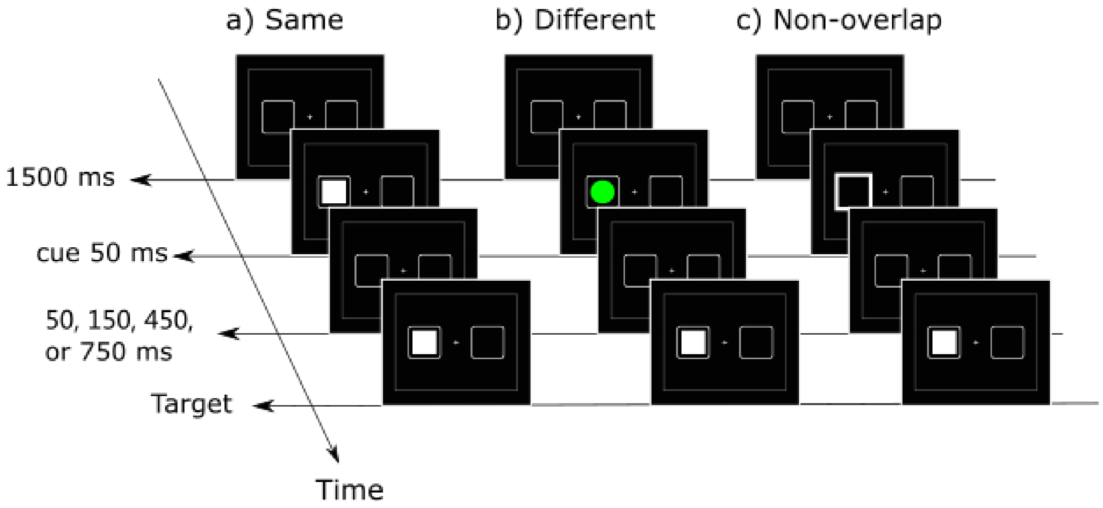


Figure 2.1. This figure is adapted from the paper by Pratt, Hillis and Gold (2001), with the alteration that the cue in the different condition is coloured. This figure provides an illustration of the design of their experiment, as well as the appearance of the cues. Except for the green cue in the *different* condition, the other stimuli (the fixation, placeholder boxes, cues, and targets) were white on a black background.

This experiment was designed to further investigate the role of cue-target discriminability in facilitation and IOR. Pratt, Hillis and Gold (2001) examined cue-target discriminability by manipulating only the appearance of the cues, while the target remained the same. In this experiment, I aimed to further examine whether and how cue-target discriminability would affect facilitation and IOR when the cue-target differences were caused by the appearance of targets, especially when the items of targets never repeated. I adopted the non-overlap condition from the experiment by Pratt, Hillis and Gold (2001) as a control condition (white cues and targets) for the novel cue condition and novel target condition. There is evidence to suggest that training with exogenous attention can enable the acquisition of learning (Szpiro & Carrasco, 2015). In each condition, with different patterns and colours, the novel stimuli were never repeated in the same block in order to avoid any associative learning between the appearance of cues and targets. This was designed to increase the discriminability of cues from targets. I hypothesised that facilitation and inhibition would be observed in all conditions as in the study by Pratt and McAuliffe (2001), because the current experiment had a similar paradigm to theirs. In addition, the novelty of the stimuli, leading to increased cue-target discriminability compared with the control condition, should affect the pattern of reaction times for short SOAs, but not for long SOAs. In other words, facilitation but not inhibition effects should be affected. Since I introduced novel stimuli, the question of whether the novelty of the cues or the targets influences facilitation and inhibition is of interest. I will look at this question in the data analysis.

2.2 Method

Participants

A total of N =11 neurotypical young adults (18 - 30 years old, students at the University of Glasgow) with normal or correct-to-normal vision participated in the experiment. They were naive to the purpose of the experiment. This study received ethical approval from College of Social Sciences Ethics Review Board of the University of Glasgow. Participants received £3 for their participation.

Apparatus and materials

Stimuli were presented on a colour BenQ LCD computer monitor (24 inches). The right-down button of the Black Box Toolkit served as the response button. The experiment was programmed in PsyToolkit (Stoet, 2010; 2017) and run on a standard PC. Participants were asked to place their head on a chinrest.

All stimuli were presented on a black background. A fixation cross was presented at the centre of the screen and subtended 1.2° consisting of two lines (0.22° thick), with two placeholders (0.59° in width) of dimensions 3.7° × 3.7° at either horizontal side. The placeholders indicated two target locations, 8.2° to the left and right of the fixation cross. The peripheral cue was an empty square measured 4.3° by 4.3°, composed of lines (0.6° wide) and the target was a white square subtending 1.5° × 1.5°. The centres of cue and target had the same distance from the fixation cross as the placeholder; see Figure 2.2. The colour of the fixation cross and the placeholders were white throughout while the colour of both cue and target changed on a block-to-block basis. More specifically, the colour of target and cue were either repetitive or novel. Colours of cue and target in the repetitive condition were consistently white, while that in the novel condition were composites of different colours to assure every stimulus was novel. Additionally, in order to increase the diversity and novelty of the targets, five different shapes (circle, pentagon, cross, triangle, square) indicated by black contours were placed at the centre of novel targets. Each shape appeared on an equal number of targets; see Figure 2.3.

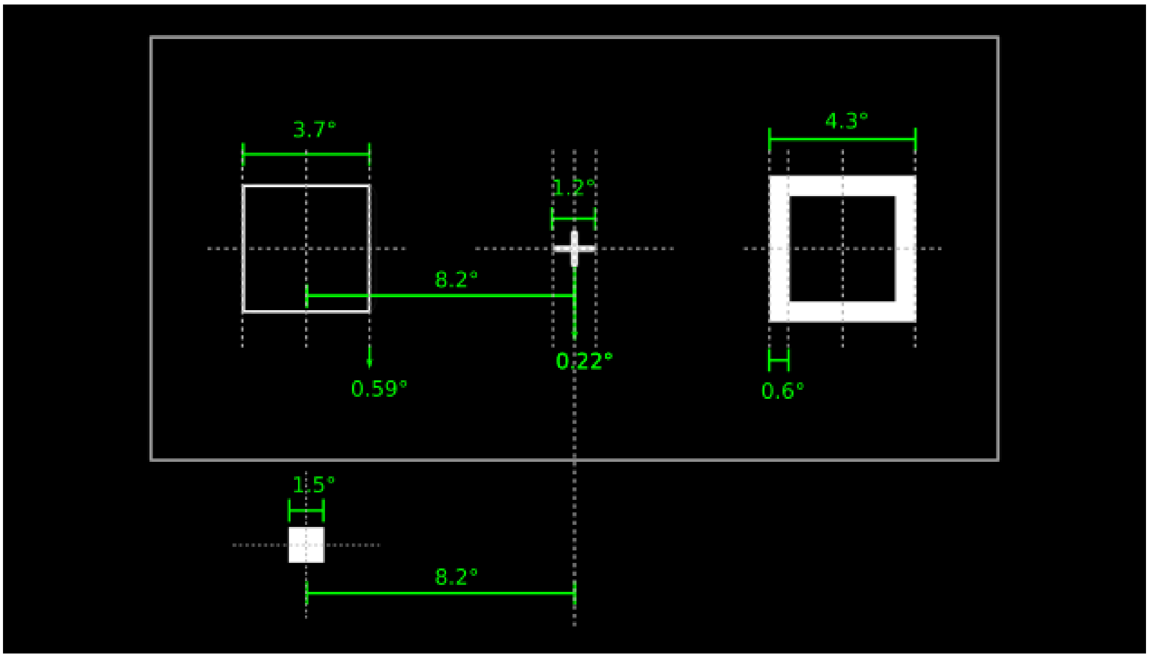


Figure 2.2. Visual angles of stimuli presented in Experiment 1. Stimuli within the big rectangle, from left to right are an example of placeholder, fixation cross and cue. The white square below the placeholder is an example of target.

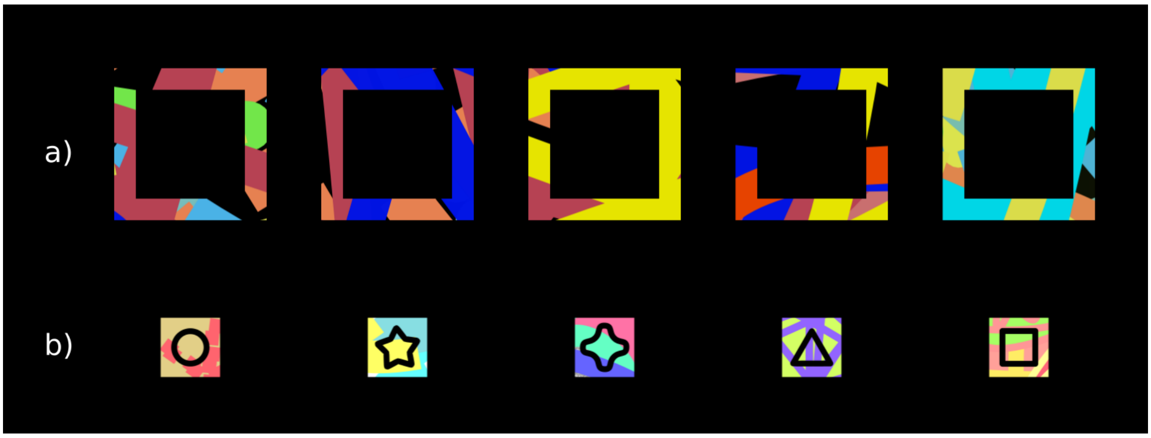


Figure 2.3. Examples of novel cues and novel targets in Experiment 1. Row a) illustrates novel cues and row b) illustrates novel targets with 5 different shapes at the centre.

Design

This study had a three-factorial design within subjects. The first factor was validity: in valid trials, targets appeared at the same location as the cue and in invalid trials targets appeared at the opposite location to the cue. These two types of trials appeared with equal probability. In addition, in catch trials a cue appeared at one location but target was not displayed afterwards. The second within-subjects factor was stimulus onset asynchrony (SOA): the presentation of the target followed the onset of the cue after an interval of 100 or 800 ms. The third factor was novelty of cue and target with four levels: 1) Repetitive cue trials were when cues were repetitive (white) following repetitive or novel (colourful) targets and 2) novel cue trials were when cues were novel while targets were novel or repetitive; 3) novel target trials were when novel target preceded by repetitive cue or novel cue and 4) repetitive target trials were repetitive target followed repetitive or novel cue. There were 160 items for trials using novel cues, 160 trials in total, and same for the novel targets. Adequate number of novel cues assured that through the whole experiment cues never repeated between any trials where novel cues were used, which applied to trials including novel targets. The order of novelty conditions was counter-balanced across blocks.

Procedure

Participants were seated 78 cm away from a computer screen with a chinrest and received verbal and written instructions to perform in trials organized as follows. The start of every trial was signalled by a 1100-ms presentation of a central fixation cross and two peripheral placeholders. Participants were instructed to fixate the fixation cross through the experiment. The peripheral cue was then presented for 80 ms on the left or right of the screen, followed by a target to the left or right, after a variable SOA (100, or 800 ms). Participants were instructed to ignore the cues.

There were two sessions with four different blocks varying in the combination of novelty of cue and target: either repetitive or novel cue paired with either repetitive or novel target; therefore there are four combinations of cue and target. Only one of these combinations appeared in one block. Each block contained 40 trials, within which 20% were catch trials, dispersed randomly across the trials. The target remained on the screen until a response was made or 750 ms had elapsed, whichever happened first (see Figure 2.4). Lack of a response in a non-catch trials as well as response on a catch trial was immediately followed by an error message (“too slow” or “too early”, respectively) while a correct response was instantly followed by a correct message (“good”). When a response was detected from the onset of a cue until the onset of a target, an error messages (“too early”) would appear promptly. Error messages were presented for 600 ms and correct messages for 300 ms. Response time (RT) to press the button was measured from target onset. All participants were asked to respond with a key-press as fast and as accurately as possible. A total of 10 practice trials (consisting of repetitive cue and target trials) were run at the beginning. Each participant completed 320 trials over 8 blocks.

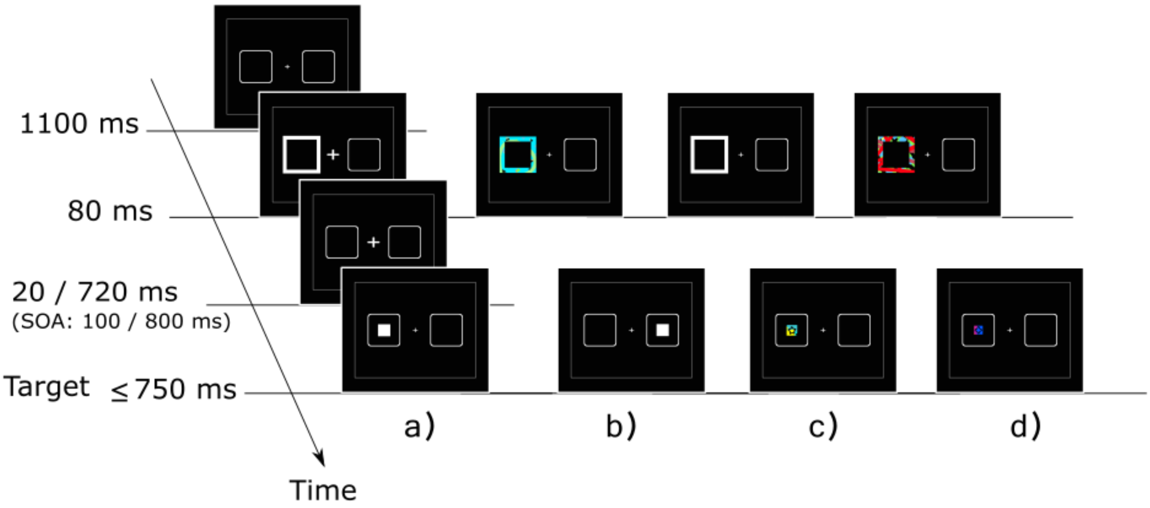


Figure 2.4. Time course of stimulus presentation in Experiment 1. Column a) illustrates a valid trial, with a repetitive cue and target. Column b) illustrates an invalid trial, with a novel cue and a repetitive target. Column c) illustrates a valid trial, with a repetitive cue and a novel target. Column d) illustrates a valid trial, with a novel cue and target.

Data Analyses

In addition to the analysis of variance (ANOVA), two statistical approaches were applied to the data of this experiment: Generalized Linear Mixed Models (GLMM). In addition to the reported *p*-values, I also computed Bayes factors (Morey & Rouder, 2018) to establish the odds in favour and against the null hypotheses. Error trials and catch trials were excluded from the RT analyses (ANOVAs, GLMMs, and Bayes factors).

2.3 Results

Descriptive Statistics of Reaction Times

As shown by the QQ plots (Figure 2.5) and violin plots (Figure 2.6), the distributions of single-trial raw RTs in the current experiment were skewed, violating the assumption of normality. Nevertheless, as previous studies have used ANOVAs for RT data analyses, I first conducted ANOVAs in order to compare results with previous studies. Then I employed GLMMs which fitted the skewed RT data using the Gamma Distribution as the link function.

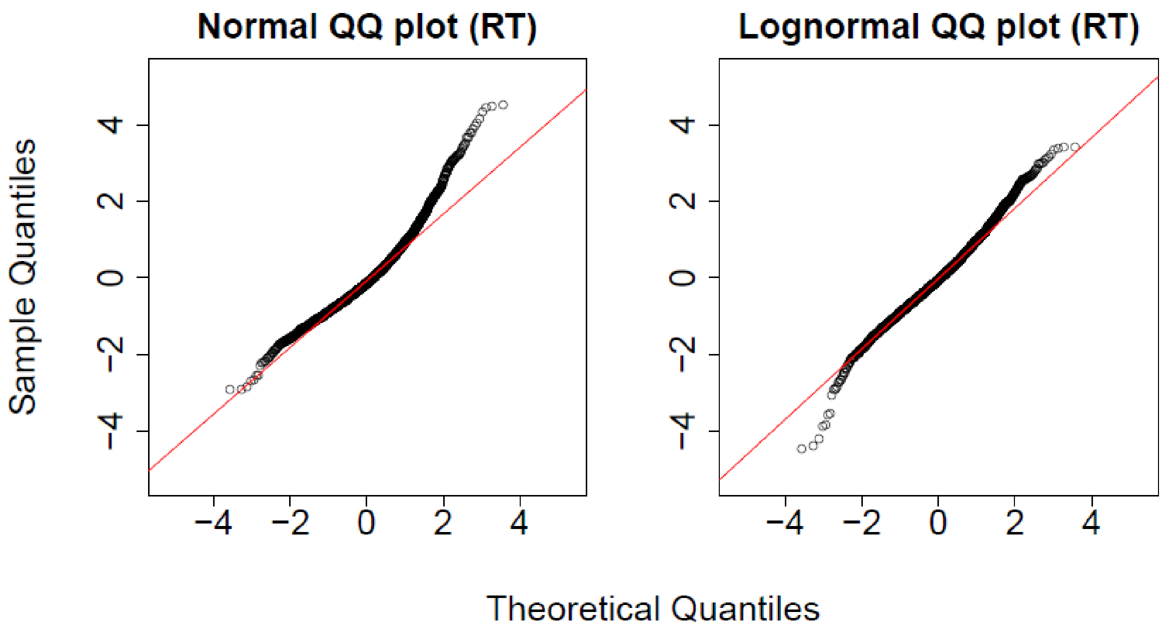


Figure 2.5. Experiment 1. Quantile-quantile (QQ) plots. The left and right QQ-plot compare sample RT quantiles with normal and lognormal distributions.

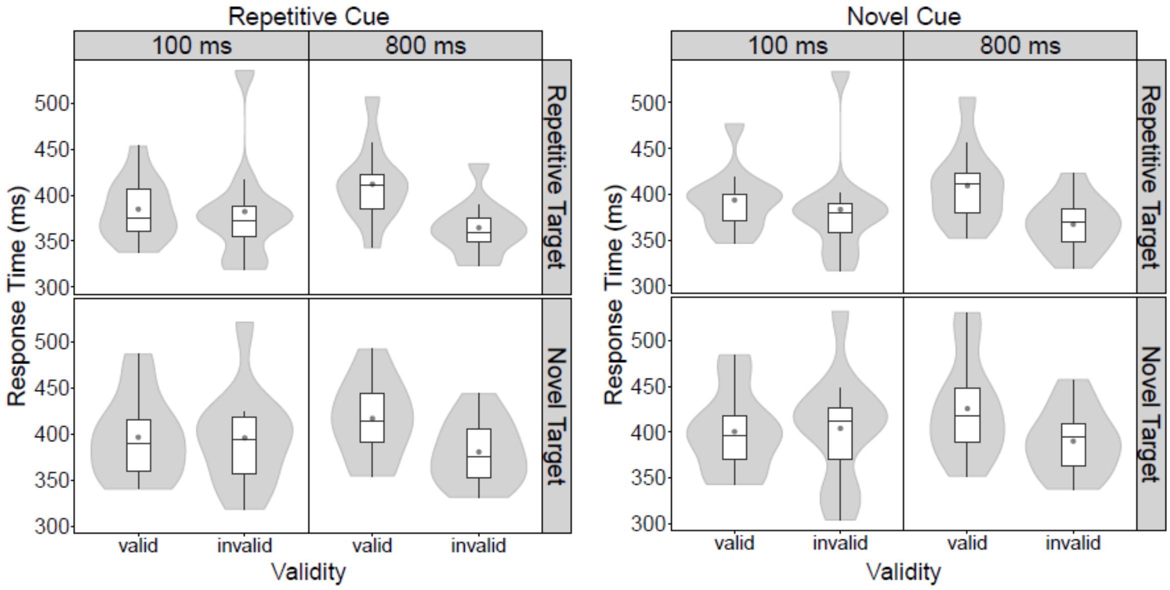


Figure 2.6. Experiment 1. Violin plots of single-trial reaction times for all conditions. The left plot shows mean values for repetitive cues and the right plot shows mean values for novel cues. Each violin plot from left to right shows mean values for the conditions with SOA of 100 and 800 ms. Each violin plot from top to bottom shows mean values for repetitive and novel targets. Mean RTs (ms) are presented as boxplots. The lower and upper hinges correspond to the 25th and 75th percentiles. The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black point represents the mean. The outlines in the violin plot illustrate kernel probability densities.

ANOVA on Reaction Times

A repeated-measurement ANOVA, with three factors (Cue Novelty, Target Novelty, SOA and Validity), was conducted on mean RTs. A significant effect of Target Novelty was found, $F(1, 10) = 14.59$, $p = .003$, $\eta_p^2 = 0.593$. Mean RTs decreased by 14 ms in trials with repetitive targets compared to trials with novel targets. A significant effect of Validity was found, $F(1, 10) = 19.91$, $p = .001$, $\eta_p^2 = 0.666$.Mean RTs invalid trials were 21 ms slower than in invalid trials. A significant interaction of SOA by Validity was found, $F(1, 10) = 11.70$, $p = .01$, $\eta_p^2 = .539$, and was investigated using pairwise one-sample *t*-tests. The results showed faster responses (-18 ms, $p = .01$) to valid trials with 100 ms SOA, faster responses (-40 ms, $p < .001$) to valid trials with 800 ms SOA than the invalid trials with 800 ms SOA; and faster responses (+22 ms, $p = .01$) to valid trials with 100 ms SOA than the valid trials with 800 ms SOA.

The following tests examined the main hypotheses (*t*-test, *p*-value adjusted after Bonferroni; Bayes Factor). The first series of testing were regarding the novel cues, more specifically, the effect of the novelty of cues on facilitation and IOR and the effect of cue-target discriminability caused by cues on facilitation and IOR. The testing of these two effects were done by comparing repetitive cues against novel cues. The differences between them were that the former one did the comparison regardless of the target novelty, whereas the latter on did the comparison only on condition of when targets were repetitive. Specifically, the former one compared the repetitive-cue condition against the novel-cue condition, while the latter one compared the condition of repetitive cue and target against the condition of novel cue and repetitive target.

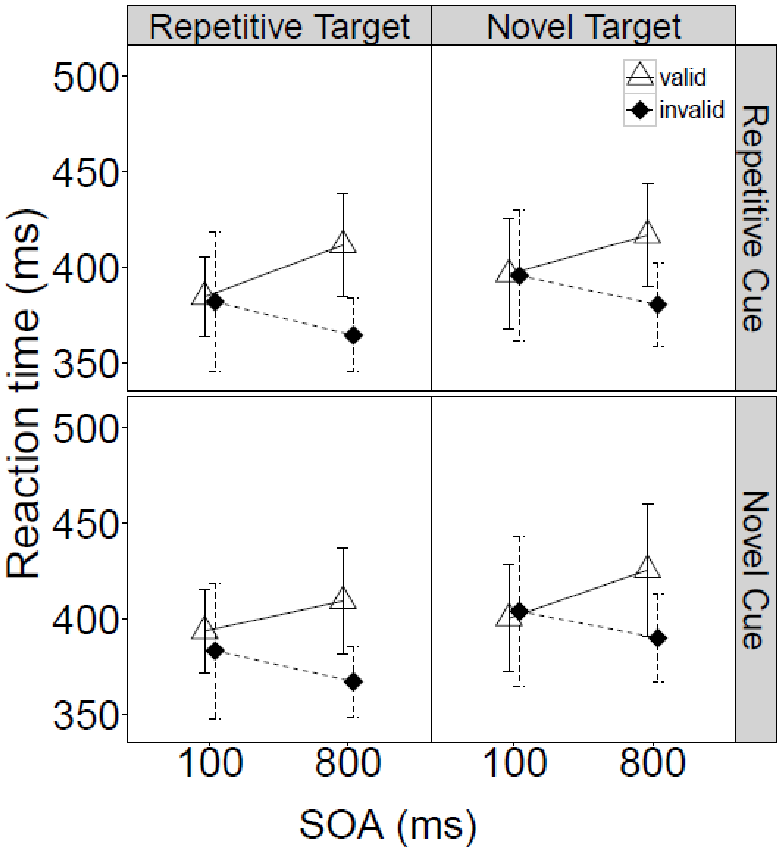
First for examining the effect of the cue novelty on facilitation and IOR, I tested whether there were any facilitation and/ or IOR when cues were repetitive or novel, regardless of the novelty of targets. The results showed that responses to trials of invalid condition relative to valid condition with 100 ms SOA were even negative, though not significantly, with both repetitive (-2 ms, $p > 0.05$, $BF_{01} = 4.39$) and novel cues (-3 ms, $p > 0.05$, $BF_{01} = 3.94$); however, responses to trials in invalid condition were significantly faster to trials in valid condition with 800 ms SOA with repetitive cues (-41 ms, $p < .001$) and novel cues (-39 ms, $p = .02$). These confirmed no facilitation but IOR with two types of cues. The next examination was for testing whether there were differences between the IOR effects produced by two types of cues shown in the last test. The results showed that there were no significant differences between them ($BF_{01} = 3.90$).

Further tests were conducted to examine the effect of cue-target discriminability caused by cues on facilitation and IOR by comparing trials with repetitive cues and targets against trials with novel cues and repetitive targets. The results (*t*-tests, *p*-value adjusted after Bonferroni; Bayes Factor) revealed that when targets were repetitive, whether cues were repetitive or novel, responses to trials of invalid condition relative to valid condition with 100 ms SOA were even negative, though not significantly, (repetitive cues, -3 ms, $p > 0.05$, $BF_{01} = 3.28$; novel cues, -10 ms, $p > 0.05$, $BF_{01} = 1.96$), suggesting no facilitation effect. However, when cues and targets were repetitive, responses in invalid trials were faster than in valid trials (-57 ms, $p = .003$), which confirmed IOR observed in this conditions. By contrast, when targets were repetitive and cues were novel, responses in invalid trials were not significantly faster than in valid trials (-43 ms, $p = 0.16$, $BF_{10} = 31.31$). Since IOR was only observed in one condition, I did not compare IORs.

The second series of testing were regarding the novel targets, more specifically, the effect of the novelty of cues on facilitation and IOR and the effect of cue-target discriminability caused by cues on facilitation and IOR. Similar to the first series of testing, the testing of these two effects of targets novelty were both comparing repetitive cues against novel targets. The differences between them were that the former one did the comparison regardless of the cue novelty, whereas the latter on did the comparison only on condition of when cues were repetitive. Specifically, the former one compared the repetitive-target condition against the novel-target condition, while the latter one compared the condition of repetitive cue and target against the condition of repetitive cue and novel target.

First, for examining the effect of the target novelty, I tested whether there were any facilitation and IOR when targets were repetitive or novel, regardless of the novelty of cues. The results showed that responses to trials of invalid condition relative to valid condition with 100 ms SOA were not significantly different with both repetitive (-6 ms, $p > 0.05$, $BF_{01} = 3.05$) and novel targets (2 ms, $p > 0.05$, $BF_{01} = 4.40$); however, responses to trials in invalid condition were significantly faster to trials in valid condition with 800 ms SOA with repetitive targets (-45 ms, $p = .004$) and novel targets (-36 ms, $p = .02$). These confirmed no facilitation but IOR with two types of targets. The fourth examination was for testing whether there were differences between the IOR effects produced by two types of targets shown in the last test. The results showed that there were no significant differences between these two IOR effects ($BF_{01} = 2.02$).

Further tests were conducted for examining the effect of cue-target discriminability caused by targets on facilitation and IOR by comparing the conditions of repetitive cues and targets against the condition of repetitive cues and novel targets. The results (*t*-tests, *p*-value adjusted after Bonferroni; Bayes Factor) revealed that when cues were repetitive, whether targets were repetitive or novel, responses to trials of invalid condition relative to valid condition with 100 ms SOA were even negative, though not significantly (repetitive targets, -3 ms, $p > 0.05$, $BF_{01} = 3.28$; novel targets, -1 ms, $p > 0.05$, $BF_{01} = 3.35$), which showed no facilitation effect. However, responses to invalid trials were faster than valid trials when targets were repetitive (57 ms, $p = .003$) and novel (36 ms, $p = .002$), which confirmed IOR observed in these two conditions. I then compared between these observed IORs (*t*-tests, *p*-value adjusted after Bonferroni; Bayes Factor) and results showed that there were no significant differences between them ($p > 0.99$; $BF_{01} = 1.59$), see Figure 2.7.



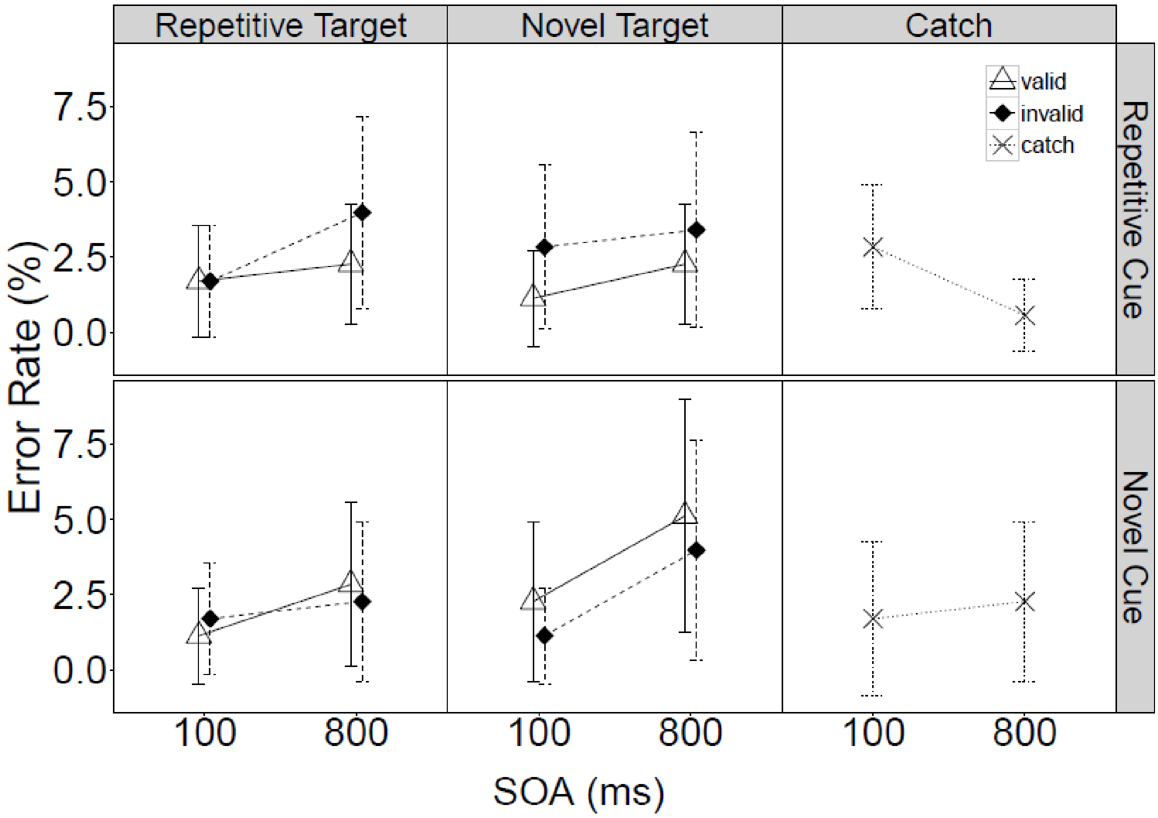


Figure 2.7. Mean RTs (ms) and ERs (%) averaged across subjects from Experiment 1. The line graphs on the top panel show response times and the line graphs on the bottom panel show mean error rates. Error bars denote ±1.96 SEM.

Descriptive Statistics of Error Rates

Participants committed false alarms in 0.23% of the target-absent catch trials. In stimuli-present trials, participants responded during the onset of cues and the onset of targets ("too early") on 0.94%, failed to respond within 750 ms ("too late") on 0.99% of the trials and pressed key earlier than 150 ms on 0.20%. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 2.7 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 2.7 will not add up to the overall error rate.

GLMM on Reaction Times

The tested models always included Cue Novelty, Target Novelty, SOA, Validity, and their interaction as fixed effects. The random factors includes not only Subjects but also items of cue (called Cue.ID) and items of targets (called Target.ID) for the reason that the items of novel cues and targets never repeated. All models have random intercepts for each item of cue and target. Therefore, the models take into account that responses to different items of cue and target may differ. Model 2 includes a random intercept for each subject so that it takes into consideration that participants may vary in their average response times. All models have random slopes to subject-specific effects of SOA and Model 3 includes additional random slopes to model subject-specific effects of Validity. The inclusion of these random slopes relaxes the assumption that the fixed effect of SOA or/ and Validity would be the same across participants. The results for all models are summarized in Table 2.1.

Table 2.1

Model comparison of models with increasingly complex random-effects structures (*df*: the number of parameters in the model, involving the coefficients of the fixed effects of the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood test between models)

Models	*df*	AIC	BIC	log-likelihood	χ^2	df_{χ^2}	*p*-value
M1: RT ~ Cue Novelty * Target Novelty * SOA * Validity + (0 + SOA | s) + (1 | Cue.ID) + (1 | Target.ID)	22	30565	30695	-15260			
M2: RT ~ Cue Novelty * Target Novelty * SOA * Validity + (1 + SOA | s) + (1 | Cue.ID) + (1 | Target.ID)	22	30565	30695	-15260	0	0	$\ll 0.0001$
M3: RT ~ Cue Novelty * Target Novelty * SOA * Validity + (0 + SOA + Validity | s) + (1 | Cue.ID) + (1 | Target.ID)	25	30541	30689	-15245	29.919	3	$\ll 0.0001$

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between factors ($r < 0.99$). As Model 3 has the lowest BIC (Bayesian Information Criterion) and AIC (Akaike Information criterion), I selected it as the most parsimonious model among the models tested. Model 3 includes the by-subject random slopes for SOA and Validity as well as by-cue-name random intercepts and by-target-name random intercepts.

Fixed Effects

A significant main effect of Validity was found, χ^2 (1) = 10.056, *p* = .002, for responses to trials in the valid condition were 22 ms slower than the invalid condition. A statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 22.086, *p* < .001. This interaction was further investigated in pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to trials in the invalid condition with 800 ms SOA were 20 ms faster than trials in the valid condition with 100 ms SOA (*p* = .02), 39 ms faster than trials in the valid condition with 800 ms SOA (*p* < .001).

The following tests examined the hypotheses (χ^2 Test, *p*-value adjusted after Bonferroni) were the same as in the ANOVAa. The first series of tests were regarding the novel cues, more specifically, the effect of the novelty of cues on facilitation and IOR and the effect of cue-target discriminability on the facilitation and IOR.

First I tested whether there were any facilitation or IOR when cues were repetitive or novel, regardless of the novelty of the targets. The results showed no significant differences of responses between trials in valid and invalid condition with 100 ms SOA with both repetitive and novel cues; however, responses to trials in invalid condition were significantly faster to trials in valid condition with 800 ms SOA with repetitive cues (-40 ms, *p* < .001) and novel cues (-37 ms, *p* = .001). These confirmed no facilitation but IOR for the two types of cues. The second examination was to test whether there were differences between the IOR effects produced by the two types of cues shown in the last test. The results showed that there were no differences between them.

Further tests were conducted to examine the effect of cue-target discriminability caused by cues on facilitation and IOR by comparing the conditions with repetitive cues and targets against the condition with novel cues and repetitive targets. The results (χ^2 Test, *p*-value adjusted after Bonferroni) revealed that when targets were repetitive, whether cues were repetitive or novel, there were no significant differences between responses time to valid and invalid trials with 100 ms SOA, which showed no facilitation effect. By contrast, responses in invalid trials were faster than in valid trials when cues were repetitive (-45 ms, *p* < .001) and novel (-40 ms, *p* = .004), which confirmed IOR observed in these two conditions. I then compared the observed IORs (χ^2 Test, *p*-value adjusted after Bonferroni) and the result shows that there was no significant difference between them (*p* > .99).

The second series of tests considered novel targets, more specifically, the effect of the novelty of cues on facilitation and IOR and the effect of cue-target discriminability caused by cues on facilitation and IOR, same as the second series of tests for hypotheses following the ANOVA.

In order to examine the effect of target novelty, I tested whether there were any facilitation and IOR when targets were repetitive or novel. The results showed no significant differences of responses between valid and invalid trials with 100 ms SOA with both repetitive and novel targets; however, responses to trials in invalid condition were significantly faster to trials in valid condition with 800 ms SOA with repetitive targets (-43 ms, $p < .001$) and novel targets (-35 ms, $p = .003$). These confirmed no facilitation but IOR for the two types of targets. The last examination was to test whether there were differences between the IOR effects produced by the two types of targets shown in the last test. The results showed that there were no differences between these two IOR effects.

Further tests were conducted for examining the effect of cue-target discriminability caused by targets on facilitation and IOR by comparing the conditions of repetitive cues and targets against the condition of repetitive cues and novel targets. The results (χ^2 Test, *p*-value adjusted after Bonferroni) revealed that when cues were repetitive, whether targets were repetitive or novel, there were no significant differences between responses time to valid and invalid trials with 100 ms SOA, which showed no facilitation effect. However, responses to invalid trials were faster than valid trials when targets were repetitive (- 45 ms, $p < .001$) and novel (- 35 ms, $p = .02$), which confirmed IOR observed in these two conditions. I then compared the observed IORs (χ^2 Test, *p*-value adjusted after Bonferroni) and the tests showed that there were no differences between them ($p > 0.99$), see Figure 2.8.

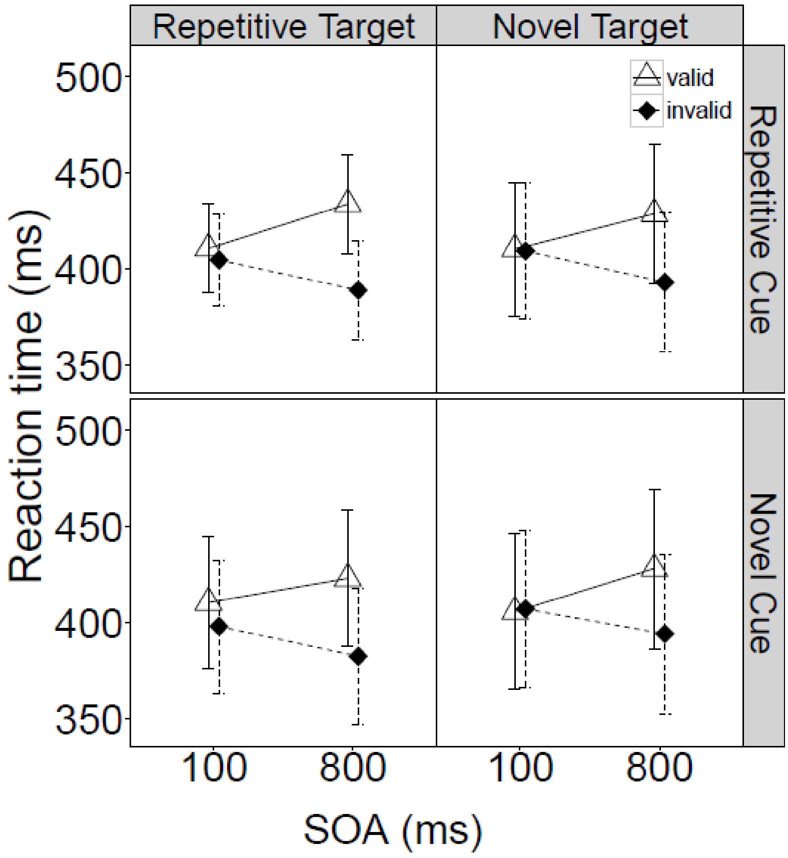


Figure 2.8. The adjusted mean RTs (ms) of Experiment 1 returned from mixed Model 3 for RT. The line graph shows response times. Error bars represent the 95% confidence intervals of the adjusted means.

Random Effects of RTs

Based on the model estimates, the individual variability of SOA and Validity, the variability of intercept of each item of cues and targets was computed. Figure 2.9 shows the conditional modes of the 11 participants, sorted by the values of 100 ms SOA. Figure 2.10 shows the conditional modes of the 161 cue items, sorted by the values of intercept. Figure 2.11 shows the conditional modes of the 161 target items, sorted by the values of intercept. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects.

The results suggested that individual differences were far more prominent for SOA 100 ms (*SD* = 17.79) and SOA 800 ms (*SD* = 14.72) than for Validity (*SD* = 4.90), whereas variability between cues (*SD* = 14.38) and targets (*SD* = 14.49) was comparable. This suggests that the random effect of SOA 100 ms explained 13 times and SOA 800 ms 9 times more variance than the random effect of Validity. This indicates that individual differences in SOA 100 ms were prominent as well as SOA 800 ms, compared to individual differences in validity condition, as shown in Figure 2.9. Variation due to cue and target stimuli was also substantial.

For the random effects respectively for stimuli of cues and targets, Figure 2.10 and Figure 2.11 depicts that responses to trials with different cues varied moderately in their averaged RT (Intercept) form the overall mean RTs as almost all the error bar overlap the zero line, which represents the overall mean RT, shown as the zero lines in the plots for Intercept. Interestingly but not surprisingly, responses to the repetitive cue (c00 in Figure 2.10) and target (t00 in Figure 2.11) are both noticeably faster than the mean RTs. Responses to the rest of cues and targets, except for one novel cue (c22) which only just deviated from the zero line, are not significantly different from the mean RT. The reason for the fact that compared to novel stimuli, repetitive stimuli deviated significantly from the zero line is most likely due to the increased number of observations. While all the novel cues made up half of all trials, the repetitive cues took up the other half, and the same applies to repetitive and novel targets. Thus, due to the much larger number of observations, the 95% confidence intervals for repetitive stimuli are smaller than for novel stimuli, as shown in both figures. Responses to repetitive stimuli were noticeably faster than the mean RTs but some novel stimuli seem to be even faster than the repetitive stimuli.

The dotplots (Figure 2.9, 2.10, and 2.11) are the visualization of the variance across subjects for random intercepts and slopes. The further the points in a plot deviate from the vertical lines, the more the variance is explained by the random intercept or slope, which means that the variability of individuals, cues or targets is more prominent for the random intercept or slope. This applied to all the dotplots of random effects in this thesis.

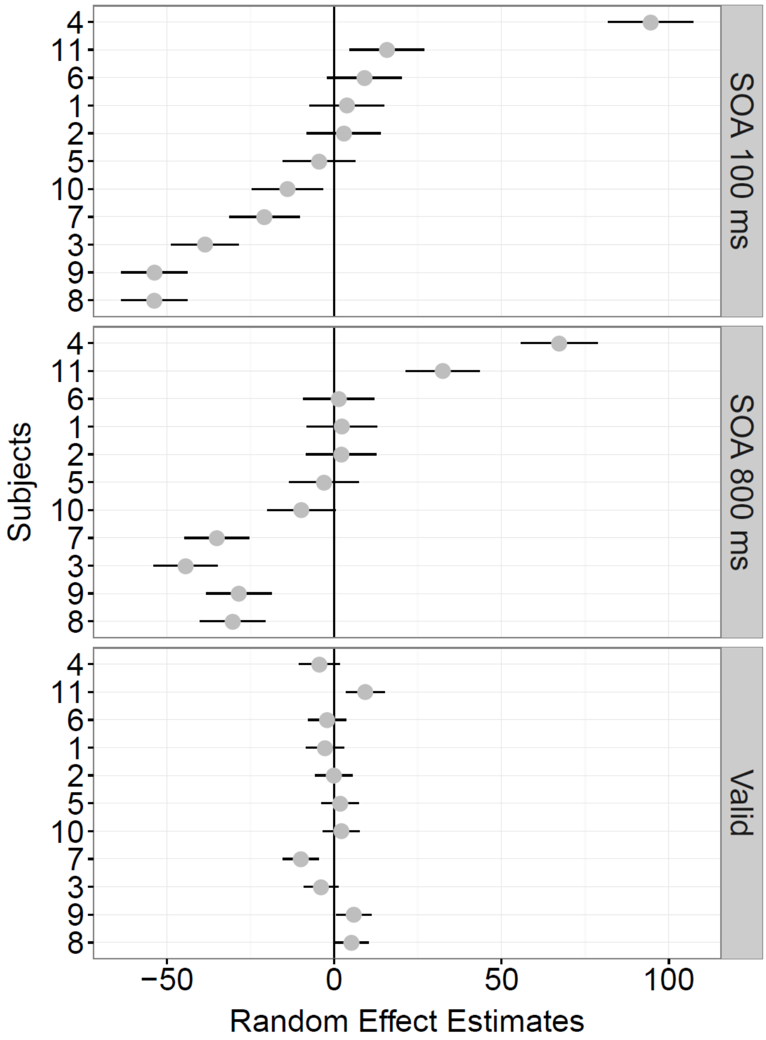


Figure 2.9. Visualization of the variance across subjects. Dotplots of random effects for each participant in Experiment 1. The plots from top to bottom show individual estimates of random slopes for SOA 100 ms, SOA 800 ms and Validity, respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 100 ms was calculated by comparing the mean of the SOA 100 ms against the overall mean of the SOA. The vertical lines centred on 0 represent the corresponding fixed effect estimate in each plot, -0.99 ms for SOA 100 ms, 0.99 ms for SOA 800 ms, and mean slope of 10.82 ms for Validity. Each dot represents a conditional mean for each participant, showing how much each individual deviates from the corresponding fixed effect in each plot. Each horizontal error bar of dots represents the corresponding 95% confidence interval. Participants are rank-ordered by their random slopes for SOA 100 ms. In short, the dotplots show that individual differences were far more prominent for SOA 100 ms and 800 ms than for Validity.

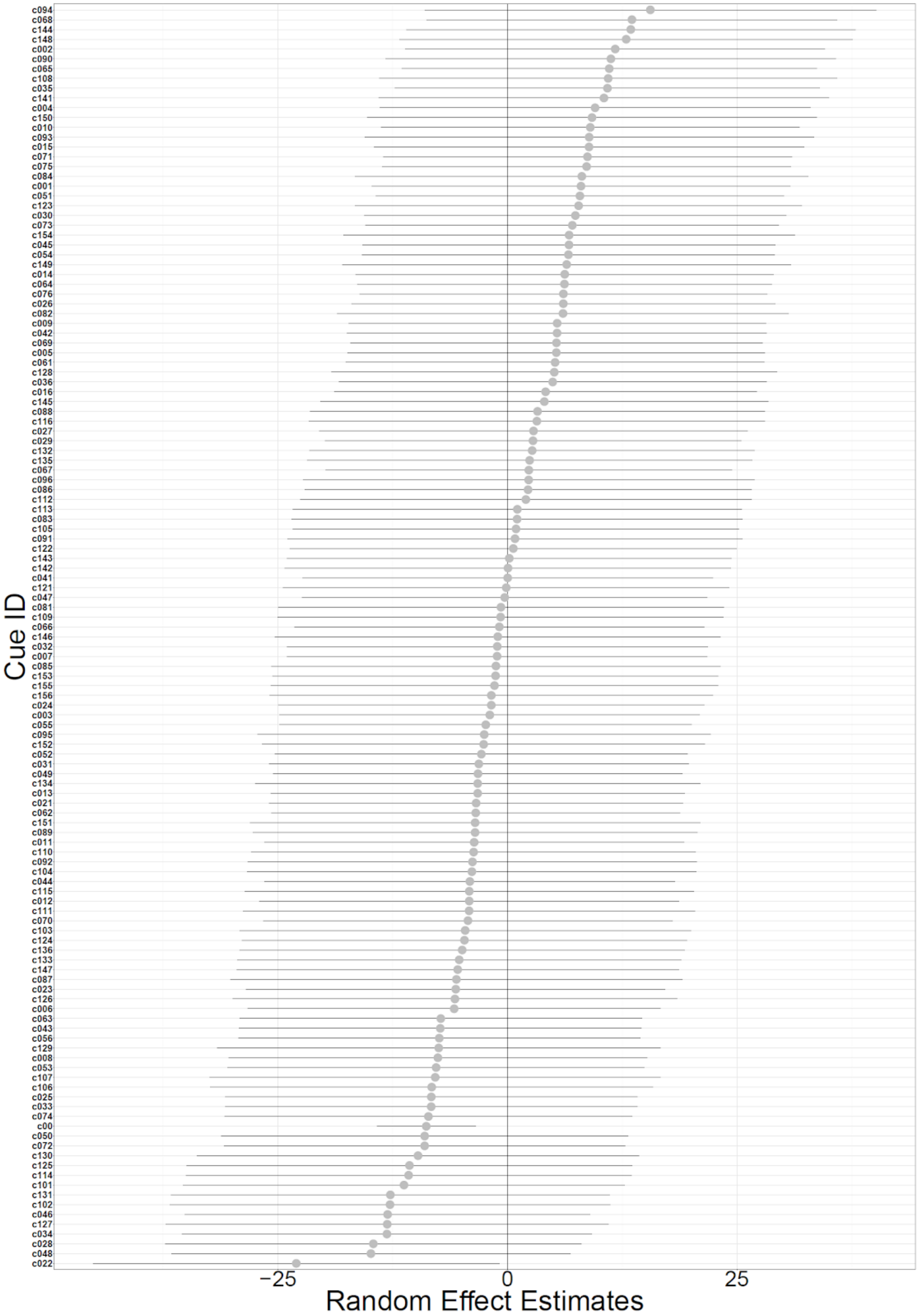


Figure 2.10. Visualization of the variance across cues. Dotplots of by-item random effects for each cue in Experiment 1. The plots show estimates of random intercepts for each cue across subjects. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. The vertical lines centred on 0 represent the overall mean RT (408.20 ms). Items of cues are rank-ordered by the random intercepts.

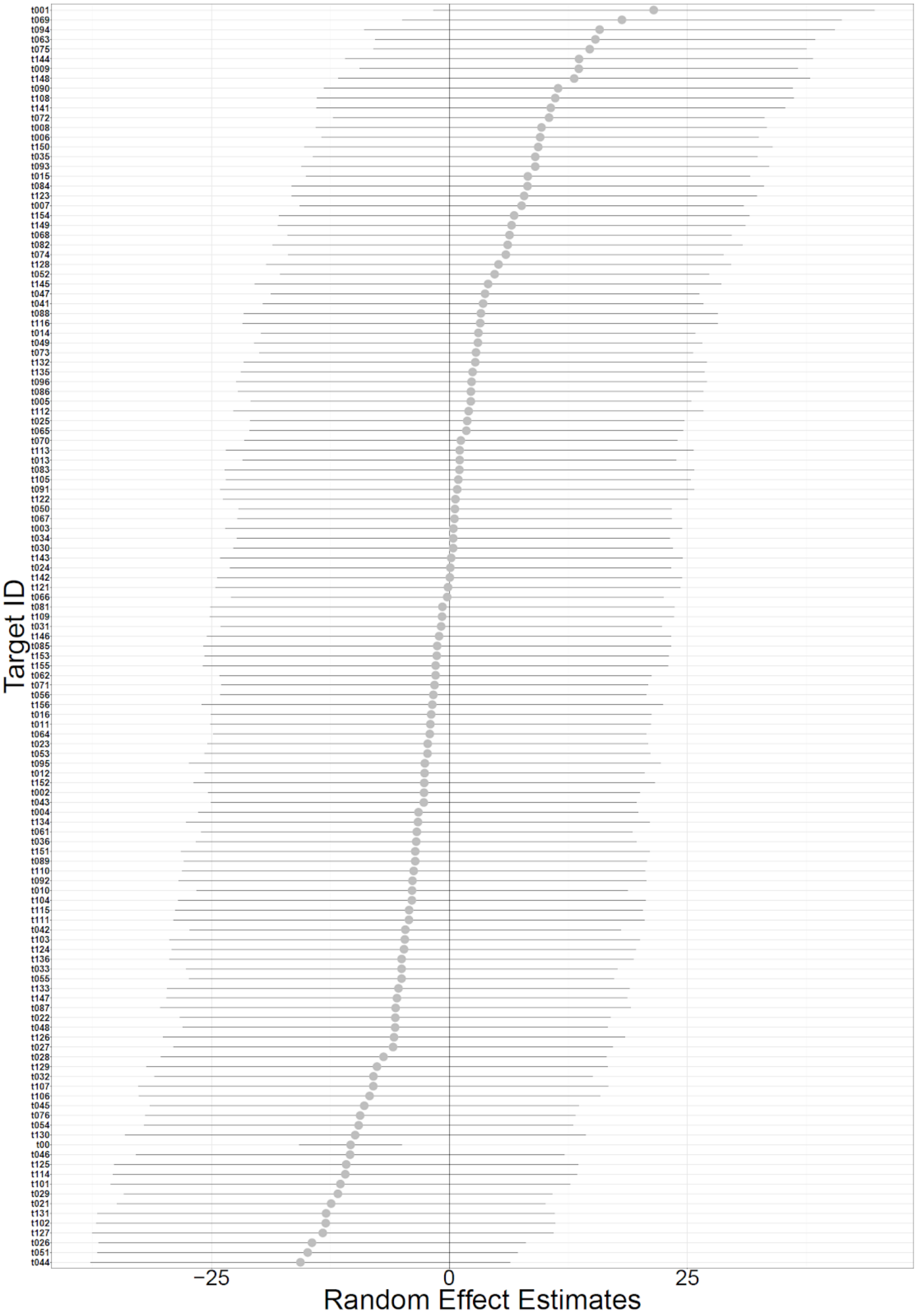


Figure 2.11. Visualization of the variance across targets. Dotplots of by-item random effects on RTs for each target in Experiment 1. The plots show estimates of random intercepts for each target. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. The vertical lines centred on 0 represent the overall mean RT (408.20 ms). Targets are rank-ordered by random intercepts.

2.4 Discussion

Pratt and McAuliffe (2001) examined the effect of discriminability between cues and targets on facilitation and inhibition of return. They suggested that the physical characteristics of cues and targets influence the pattern of reaction times for short SOAs (facilitation), but not for long SOAs (IOR). Pratt, Hillis and Gold (2001) investigated cue-target discriminability by manipulating only the appearance of the cues while the targets remained the same. This experiment aimed to further investigate whether cue-target discriminability affects facilitation and IOR, especially when differences between cue and target are due to variability in the appearance of the targets. The stimuli never repeated in one block (novel condition), which was designed to prevent learning an association between cues and targets. Therefore, to lead to stronger discrimination between cues and targets. In addition, I investigated whether novelty of the stimuli will influence facilitation and IOR.

The random effects of GLMM revealed that individual differences were far more prominent for SOA 100 ms and 800 ms than for Validity, whereas variability between cues and targets was comparable, as shown by the dotplots. Since the random effect of GLMM explained sufficient variance across subjects, cues and targets, it improved the estimates of fixed effects by controlling the inherent noise brought by different individuals as well as different cues and targets.

2.4.1 Summary of Results for Cue-target Discriminability

In regard of of the effect of cue-target discriminability on facilitation and IOR, I only observed IOR but not facilitation, as confirmed by the GLMM. Furthermore, for the short SOA, responses to targets in the invalid condition were only a few milliseconds (no more than 10 ms) faster than responses to targets in the valid condition for repetitive cues followed by repetitive targets, repetitive cues followed by novel targets, and novel cues followed by repetitive targets, and did not reach statistical significance. Furthermore, in these conditions, the Bayes factor favoured the null hypothesis. The null hypothesis was about 2 or 3 times stronger than the alternative hypothesis, suggesting no facilitation.

In contrast to facilitation, I observed IOR in the condition with repetitive cues and targets and in the condition with repetitive cues and novel targets, confirmed by both ANOVA and GLMM. However, the evidence of IOR generated by the condition with novel cues and repetitive targets was not consistent. The GLMM confirmed the presence of IOR and the Bayes factor provided very strong evidence in favour of IOR as evidence for the alternative hypothesis was 31 times more likely than the null hypotheses. In contrast the ANOVA suggested that the IOR was not significant. The absence of a statistically significant effect in the ANOVA is probably due to unaccounted noise across items and individuals. In terms of the effects of cue-target discriminability on IORs, easier discriminability caused by either cues or targets did not affect the IOR, which is in line with the conclusion suggested by Pratt and McAuliffe (2001). Lastly, the fixed effects of the GLMM were very similar to the results of the ANOVA. This means that controlling for random effects in stimuli and subjects did not change the effects. The absence of facilitation for short SOA, for example, was not due to increased noise from the introduction of novel cues and targets.

2.4.2 The Absence of Facilitation

If there were one condition in which one would observe facilitation, then this would be the condition with repetitive cues and targets. This is because the procedure and design in this condition was similar in many aspects to those used in Pratt et al. (2001) and McAuliffe and Pratt (2005), where facilitation was observed. For example, the condition of repetitive cues and targets in this experiment and theirs have two peripheral locations for cues and targets, no spatial and temporal overlap, the same features of cues (empty square) and targets (filled-in square), the same cue-target discriminability, the same temporal setting (50 ms cue duration and 100 ms SOA). It is reasonable to assume that Pratt and et al. (2001) observed facilitation, because they used a discrimination task, for which facilitation is more easily observed as for a discrimination task. However, the tasks in the studies by McAuliffe and Pratt (2005) were also detection tasks, and they still observed facilitation for a short SOA. A number of experiments failed to generate early facilitation when using peripheral cues (e.g., Prime et al., 2006; Riggio, Bello, & Umiltà, 1998; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994). It is possible that the fragility of facilitation is due to its sensitivity to specific experimental tasks and design. Facilitation appears within a short time window is possibly more related to low level processing, which is more sensitive to the whole presentation of stimuli such as the luminance of the screen background. On the one hand, although I controlled the factors that are considered to be important for facilitation, it is likely that some smaller factors were not taken into account. On the other hand, it is hard to produce a completely identical set-up as in previous experiments as only the most important details are reported in a Method section.

2.4.3 The Effect of Cue-target Discriminability

The question motivating this experiment concerned the role of cue-target discriminability in facilitation and inhibition. Although in the studies by Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi (1994) cues and targets had temporal overlap, which should favour facilitation, no facilitation was obtained. Lupiáñez and Weaver (1998) suggested a reason for failing to observe facilitation for 0 ms SOA, when the cue and target appear at the same time. They suggested that the reason could be attributed to the confusion between trials in the valid conditions (i.e., targets appear at the cue location) and catch trials (i.e., cues appear without targets) because both trials have changes at only one location when cues appear. This confusion resulted not only in no facilitatory effect, but also in ‘inhibition’ at the location with cueing. In this sense, easy cue-target discriminability, which reduces this confusion, should help to bring about a facilitatory effect by cueing, especially with a short SOA. Pratt, Hillis and Gold (2001) did find that cue-target discriminability affects response patterns with a short SOA, although not with a long SOA. As for short SOA facilitation was only observed in the condition with the easiest cue-target discriminability (no spatial overlap between cues and targets).

The present work, however, did not show that easier cue-target discriminability favoured facilitation caused by cueing, as easy cue-target discriminability (i.e., either cues or targets were novel) showed the same non-significant facilitation as the more difficult cue-target discriminability condition (i.e., repetitive cues and targets). Notice that Tassinari et al. (1998) disproved the explanation by Lupiáñez and Weaver (1998) that the delay in the valid condition was caused by the hypothesised confusion between catch trials and trials in the valid condition, as Tassinari et al. (1998) still observed early inhibition in a paradigm without catch trials. In this sense, whether or not targets are easy to distinguish from cues did not affect the occurrence of facilitation.

On the other hand, perhaps easier cue-target discriminability did help the process of distinguishing targets from cues and hence help the occurrence of facilitatory effects, but this positive effect of cue-target discriminability might have been masked by the effect of the strong sensitivity of facilitation to experiment settings; that is, the effects of unnoticed experiment settings (such as the luminance of screens) which are not in favour of the occurrence of facilitation are stronger than the positive effect produced by easier cue-target discriminability, which help facilitation. As a result, the positive effects is not detected in this experiment.

It might also be possible that, even when cues and targets have the same colour and pattern, spatial non-overlap between cues and targets is already enough to trigger facilitation, so that extra settings lead to easier discriminability will not bring any significant benefit to the facilitation effect. In order to better investigate the facilitation effect, it may be beneficial to use experimental settings that do not trigger facilitation in the first place, such as the same and different conditions in the study by Pratt, Hillis and Gold (2001), in which cues and targets were spatially overlapping, and look at changes in facilitation, for example, in terms of occurrence and magnitude.

2.4.4 The Effect of Stimulus Novelty

For the examination of how novelty of cues or targets affect facilitation and IOR, I did not have the chance to look at the effect of novelty of stimuli on facilitation for I did not observe facilitation in all conditions, confirmed by both the ANOVAs and GLMM. Furthermore, the Bayes factor indicated substantial evidence for the absence of effects in all conditions. As indicated by the Bayes factor, evidence in favour of the null hypothesis was about 3 times stronger for repetitive targets and about 4 times stronger in other conditions than the evidence in favour of the alternative hypotheses. In contrast to facilitation, I observed IOR across all conditions. However, the IOR generated by repetitive cues was not different from the IOR generated by novel cues and this situation was the same for repetitive and novel targets.

As suggested by Pratt et al. (2001), the pattern of reaction times was affected by the physical characteristics of the stimuli for short SOAs, but not for long SOAs. Therefore, it is not surprising that the novelty of the stimuli did not have any effect on IOR. However, as no facilitation effects were observed in this experiment, the effect of stimuli novelty on facilitation remains unclear.

2.4.5 ANOVA and GLMM

Although hypothesis testing of the GLMM approximately tests effects for statistical significance, the estimates of the GLMM are likely to be more accurate than for the ANOVA for the following reasons.

Firstly, GLMM takes into account the skewed RT data, which violates the normality assumptions of a standard ANOVA. For example, for the skewed distribution of RTs in this experiment, I fitted the skewed data with a Gamma distribution instead of a Gaussian (or log-transformed) distribution.

Secondly, instead of using averaged values in ANOVA, GLMM relies on single-trial data which is across trials and subjects. Therefore, through random effects, it can explains and identify sources of variability (e.g., across items, participants) as well as reduces noise, which may improve estimation of fixed effects. Specifically, in this experiment the random effect of GLMM explains sufficient variances across subjects, cues and targets.

Lastly, in an ANOVA unbalanced designs is neglected by averaging the RTs to one single value for each condition. However, GLMMs can handle data transformations (link functions), missing data, and unbalanced designs (e.g., Kliegl et al., 2011). In my experiments, the number of trials for each condition will be unequal after excluding error trials. Therefore, using GLMM helps to handle unbalanced observation for my experiments.

Therefore, I selected the results of GLMM instead of ANOVA, that is, IOR was generated in the condition with novel cues and repetitive targets. In addition, considering the advantages of GLMM over ANOVA I will used GLMM for the data analysis of all the following experiments.

Chapter 3 On-off and Off-on Cues: The Sequence Matters

3.1 Introduction

Generally speaking, in order to survive, every being needs to keep moving, whether it moves as slowly as the roots of a tree digging through earth in search of water, or as swiftly as a puma chasing a fleeing deer. The world is dynamic, and in daily life it is common for us to see objects appearing or disappearing from our visual field. As peripheral vision is the borderland of our visual field, objects enter and exit our visual field through the periphery. The abrupt appearance of an object in our visual field captures our attention (e.g., Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Müller & Rabbitt, 1989; Yantis & Jonides, 1984, 1990). We need to quickly extract information from these visual objects, to gauge their form and size, in order to determine whether we need to take action in response to these objects. As for a disappearing object, does our attention orient us to the location where the object has vanished? Although the latter question seems less important than questions about an object's appearance, the latter question has been studied in the paradigm first suggested by Posner and Cohen (1984). Researches have always investigated the disappearance of objects together with the appearance of objects, using offset cue to study the former and onset cues to study the latter, respectively. Facilitation and Inhibition of Return (IOR) are the two typical effects observed in the classic Posner paradigm. Observing the influence of onset and offset cues on facilitation and IOR helps us to understand not only how the visual system reacts to appearing and disappearing objects, but also the characteristics and mechanisms of facilitation and IOR. In the literature, onset cues can be presented as an new item around placeholders (e.g., Riggio, Bello, & Umilta, 1998) or by brightening the placeholders (e.g., Pratt & McAuliffe, 2001). Similarly, offset cues are typically objects that disappear completely (e.g., Pratt & Hirshhorn, 2003) or are dimmed down objects such as placeholders (e.g., Posner & Cohen, 1984).

Posner and Cohen (1984) investigated the role of sensory factors in facilitation and IOR. They studied whether facilitation and IOR were due to the brightness enhancement of cues. For this purpose, they used dimming cues and brightening cues. Since dimming cues generated facilitation as brightening cues in the single-cue condition, they concluded that facilitation is not caused by brightness enhancement. As for IOR, according to the theory of attentional orientation, if IOR is caused by the orientation of attention, then facilitation should precede IOR. Since Posner and Cohen (1984) found significant IOR without significant facilitation after double cueing, they suggested that IOR arises from energy change at the cue location, instead of from attentional orientation. Since dimming cues are able to generate facilitation after single cueing, it appears that offset cues can capture attention as onset cues. More evidence came from studies using similar cues, that is, non-informative cues in the periphery. For example, as both onset and offset cues can generate facilitation and IOR, Pratt and McAuliffe (2001) concluded that the attentional system treats offset cues in the same manner as onset cues. Riggio, Bello, and Umilta (1998) also found facilitation and IOR with both onset and offset cues in their Experiment 1, and the amounts of facilitation and IOR were similar for both onset and offset cues. Furthermore, in their Experiments 2 and 3, where no significant facilitation was observed for offset cues, facilitation was also absent for onset cues. In addition, for both onset and offset cues, IORs showed the same patterns in terms of presence and absence as well as of magnitude changes even in a complex paradigm with multiple cueing, regardless of the placeholders that were present or absent (Birmingham and Pratt, 2005). In short, the results suggest that the attentional system treats offset cues similarly to onset cues and, therefore, that offset cues are able to capture attention, specifically covert and exogenous attention, in this context.

The evidence listed above was collected on occasions when onset and offset cues were presented in separate trials. Taking a step further, researchers were interested in whether the attentional system prefers onset or offset cues when the two types of cues were presented in one trial simultaneously (Pratt & McAuliffe, 2001; Pratt & Hirshhorn, 2003; Cole & Kuhn, 2010). The results suggested that onset cues may have priority over offset cues in orienting attention in a localisation task, but not in a detection task (Pratt & McAuliffe, 2001). More specifically, for the short SOA in a localisation task, when an onset and an offset cue were presented in one trial simultaneously, responses to the targets preceded by onset cues were faster than responses to the targets preceded by offset cues. This result was found in the localisation task, but not in the detection task. The authors attributed this variation to the different attentional demands of these two tasks. That is, in the localisation task, in which the attentional resources are not as sufficient as they are in the detection task, the attentional system prioritises onset cues over offset cues because the appearance of new visual information is commonly more important than the disappearance of old information. However, one problem of the study by Pratt and McAuliffe (2001) was that a baseline for the comparison of onset and offset cues was missing. In a later study, Pratt and Hirshhorn (2003) solved this problem and applied an improved version of the task by adding a baseline for better comparison. They replicated the result that the attentional system prioritises onset cues over offset cues. The tasks used in these two studies (Pratt & McAuliffe, 2001; Pratt & Hirshhorn, 2003) were similar to the peripheral cueing task used by Posner and Cohen (1984). However, the prioritisation of onset cues disappeared as the task type changed. The studies by Watson and Humphreys (1995) using visual search tasks showed that there was no prioritisation of onset cues over offset cues. In short, the evidence from peripheral cueing tasks that the attentional system prioritises onset cues over offset cues suggests that the luminance transients that accompany the cue onset capture attention more effectively than offset cues, but depend on task types.

Furthermore, researchers added on-off cues to the comparison of onset and offset cues. On-off cues are cues in which the onset of the cue is followed by its offset, see Figure 3.1. Riggio, Bello, and Umilta (1998) found that the amount of inhibition was greater for on-off cues than for the sum of the separate IORs generated by onset and offset cues. There appeared to be an interaction between onset and offset cues when they appeared at the same location successively. They speculated that, for these two IORs to occur, there could be a common neural substrate in which they are processed jointly and can strengthen each other. However, when there were more than two possible target locations, a greater IOR was observed for onset cues than for on-off cues in the studies by Birmingham and Pratt (2005). They suggested that locations preceded by onset cues are easier to encode as searched locations than locations preceded by on-off cues, indicating a role of working memory in IOR.

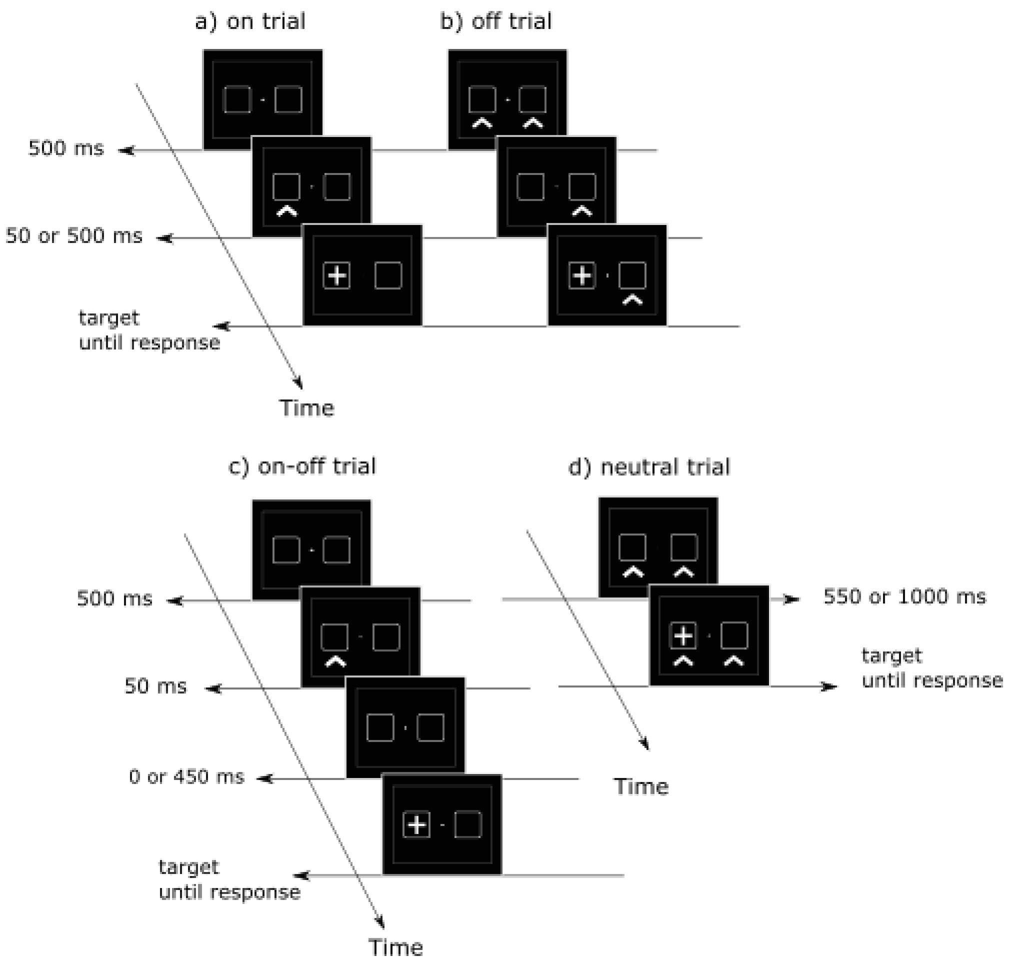


Figure 3.1. Illustration of the design of the studies (cue: on, off, on-off) by Riggio, Bello, and Umilta (1998) as well as the appearance of a cue (chevron) below the placeholder (box).

In summary, the peripheral cueing paradigm showed that offset cues can capture attention and that the attentional system treats offset cues similarly to onset cues. However, when onset and offset cues appeared in the same trial, they were treated differently. It was shown that the attentional system gave priority to onset cues over offset cues. Further results from the studies by Riggio et al. (1998) using on-off cues imply that there are interactions between onset and offset cues when they appear at the same location sequentially. Taking these results into account, one question of interest is: Will the interaction between onset and offset cues be affected by the sequence of onset and offset cues? In other words, when the offset of a cue is followed by its onset, or simply name it an ‘off-on cue’, will off-on cues have the same effects as on-off cues on IOR and facilitation? The results could further indicate how the attentional system treats the combined onset and offset cues with a reversed sequence, which is not yet clear in the literature. Therefore, on-off cues and off-on cues will be used in this experiment. In addition, I have included a condition with no cue, which provides a baseline for a comparison of the effects of on-off and off-on cue. In addition, to prevent any delay in the presentation times of stimuli due to the refresh rate of an LCD monitor, I will use light emitting diodes (LEDs) in order to increase the accuracy of the presentation times.

3.2 Method

Participants

Three participants has extremely high error rates in the condition of valid and invalid condition with on-off cueing (ranging from 30% to 41%), compared to other participants (maximum 12%). Data from these three participants was excluded before statistical analysis, leaving data from N= 20 participants (14 female, 6 male), aged 18 - 30 (mean age 22.90 ± 2.57). All had normal or correct-to-normal vision and were naive to the purpose of the experiment. This study was approved by the College of Social Sciences Ethics Review Board, University of Glasgow. Participants gave informed written consent and received a payment of £5 for their participation.

Apparatus and Materials

Stimuli were presented by three horizontally aligned light emitting diodes (LEDs) with 3 mm diameter flashed on or off in Red or Green. The right-down button of the Black Box Toolkit served as the response button. Participants were asked to place their head on a chinrest to keep viewing distance and viewing angle constant.

The experiment took place in a completely darkened room, and all stimuli were presented on a black background. At a viewing distance of 83.5 cm the three LEDs were circles of 1.7° in diameter. The LED in the middle served as fixation point, switching on in Red and off in Black. The other two LEDs were placed 8° to the left and right of the fixation LED and represented the cue and target stimulus. The cue was either the red peripheral LED being set on and followed by its offset (“on-off cue”) or the LED being set off and followed by its onset (“off-on cue”). The target was a peripheral LED switching from Black to Green; see Figure 3.2.

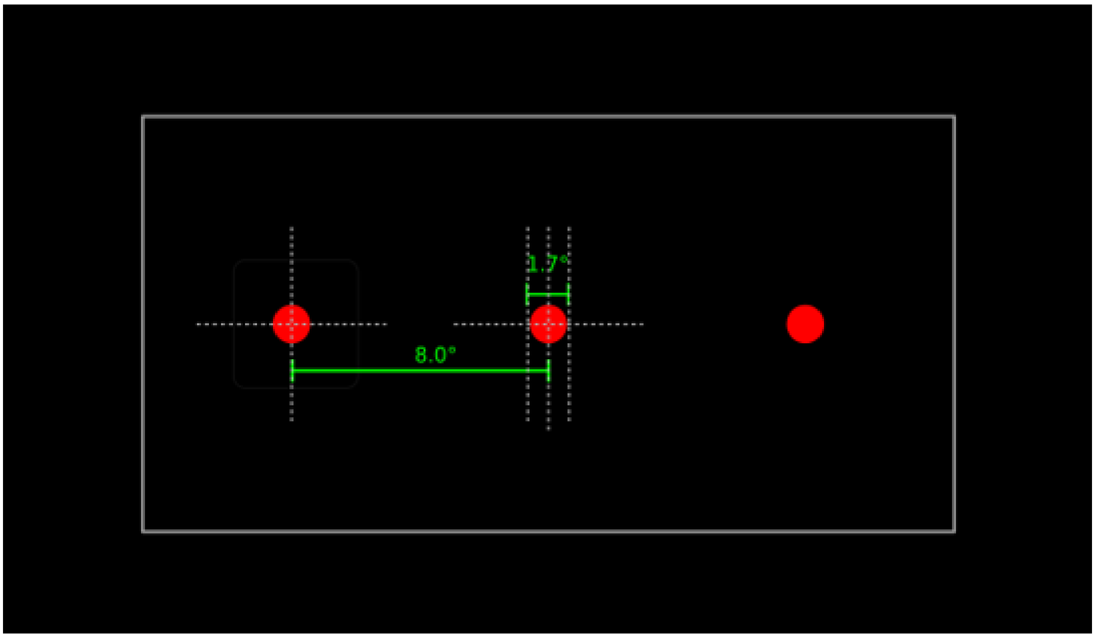


Figure 3.2. Experiment 2. Illustration of fixation and stimulus display with visual angles inserted in Green. The three LED lights s were identical in size. The LED in the middle is the fixation point and the two LEDs on either side shows the cue and target (in green). In the on-off condition, one peripheral LED is set on in red followed by its offset as a cue, and in the off-on condition, one peripheral LED is set off followed by its onset as a cue. Targets are shown by one peripheral LED in green.

Design

As in Experiment 2, this study had a within-subjects design with three factors. First, the validity of the peripheral cue was modified, with no cue appearing before a target in no-cue trials as a control condition. The SOA was also manipulated, with targets appearing 80 or 530 ms after the onset of the peripheral cue (valid or invalid trials) or 110 or 560 after the offset of the fixation point (no-cue trials). The last factor was Cue Type, with on-off trials and off-on trials. In the on-off trials, the lights on both sides were off except when the cue (red light) or target appeared. The on-off cue is one peripheral LED being set on in red followed by its offset. In the off-on trials, the two peripheral lights remained red except the cue, the light being set off, and target appeared. The off-on cue is one peripheral LED being set off followed by its onset in red. The order of on-off and off-on trials was counter-balanced between blocks and observers.

Procedure

Participants were seated 83.5 cm away from the display with their head on a chinrest so that the LEDs remained on eye-level height. The initial display was presented for 1000 ms with the middle LED on in red. The middle light was then turned off for 200 ms and on again for 200 ms. This off-and-on alternation was repeated three times served as the fixation point, drawing their attention throughout the experiment. The left or right light was then turned red as peripheral cue or for 30 ms or turned black on the no-cue trials, followed by a green light (target) to the left or right after a variable SOA of 50 or 500 ms. The maximum response time was 1000 ms. Participants were instructed to ignore any change at the two peripheral positions except for the appearance of a green light. There were two sessions in this experiment, a on-off and a off-on section. Each session consisted of two blocks, a training block and a real experiment block of 250 trials consisting of 80 valid, 80 invalid, 80 no-cue trials as well as 10 catch trials without target presentation. The training block included 15 random trials as in the experimental block, 5 of which were catch trials; see Figure 3.3. The increased proportion of catch trials in the training block should give the participants the impression that targets can be absent in order to reduce anticipating target presentations. More specifically, as the interval between the offset of fixation point and onset of target were fixed at either 110 or 560 ms, without catch trials, participants may have responded by default without detecting the target.

Each trial type occurred randomly and with the same frequency. An error message, three red lights switching on and off concurrently, would instantly follow a missed target in non-catch trials if no response was given and in a catch trial if a response was made. When a response was detected between the onset of a cue and the onset of a target, an error messages would appear immediately. A correct message was given when all three green lights switched on and off. Both the error and correct message was accompanied by a sound. Error messages were presented for 2,400 ms and correct messages for 1,600 ms. Response times (RT) were measured from the onset of a target until the response button was pressed. Participants were instructed to respond to the target as quickly and as accurately as possible by pressing button. Between two sessions, participants took a break for 5 minutes in a circumstance with high luminescence to make sure that participants undergo a dark adaptation period at the beginning of the second session as they did at the start of the first session. Each participant completed 530 trials in total.

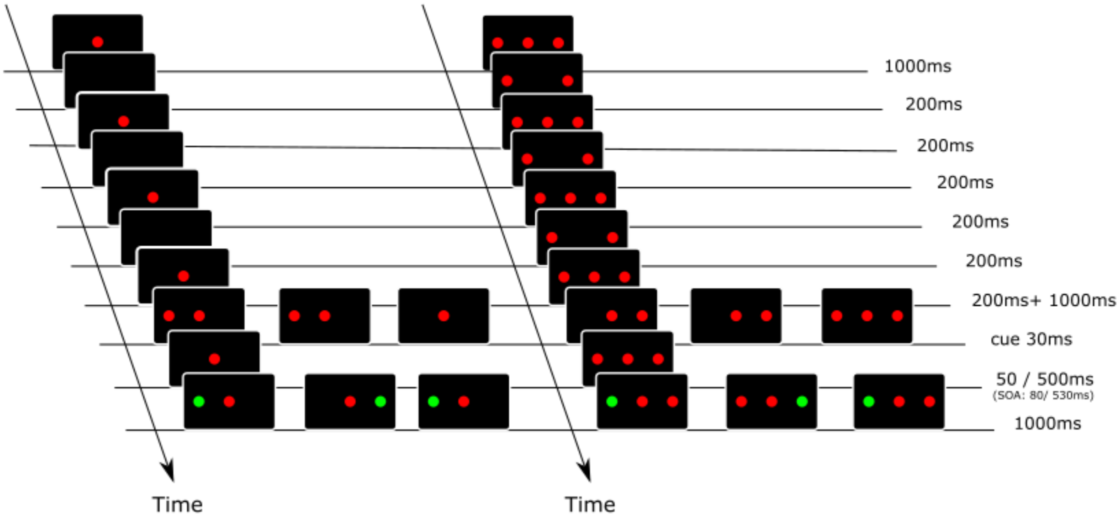


Figure 3.3. Design of Experiment 2: Illustration of time courses for cue and target presentation. The left panel shows the on-off condition and the right panel shows the off-on condition. The cue in the on-off condition is the onset of a peripheral red circle followed by its offset whereas in the off-on condition the cue is the offset of a peripheral red circle followed by its onset. The target in both condition is a green circle in the periphery.

Data Analyses

The approaches used in this experiment were the same as Experiment 1. As justified in Exp. 1 that GLMM is advantageous to ANOVA in various aspects, therefore, in Exp. 2 with a similar paradigm I conducted GLMMs on RTs. Error trials and catch trials were excluded from the RT analyses.

3.3 Results

Descriptive Statistics for Reaction Times

As shown by the QQ plots (Figure 3.4) and violin plots (Figure 3.5), the distributions of single-trial raw RTs in the current experiment were skewed, violating the assumption of normality. I employed GLMMs fitting the skewed data with Gamma Distribution.

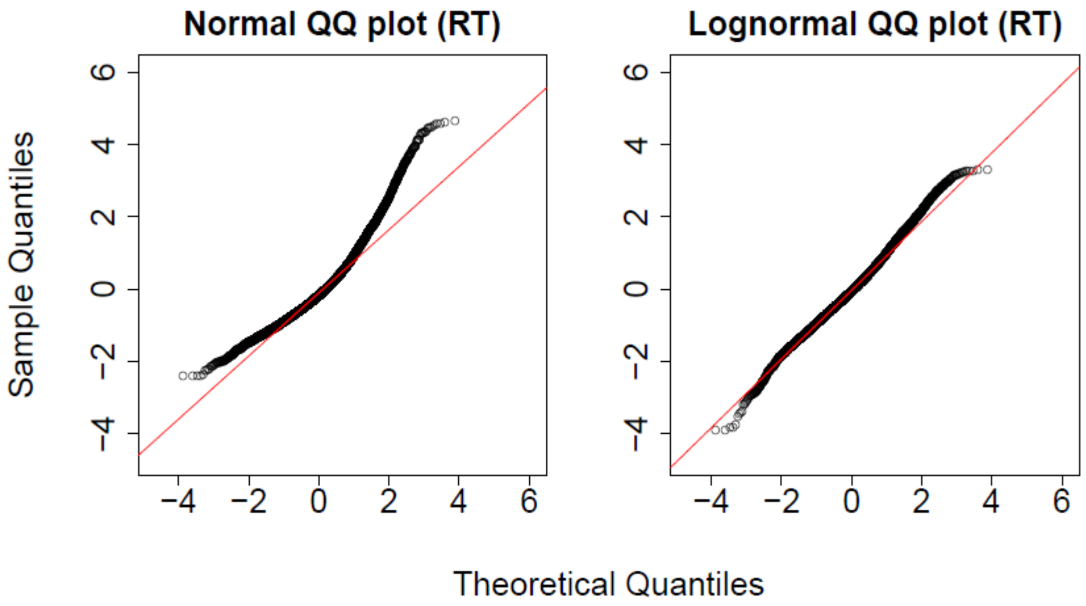


Figure 3.4. Experiment 2. Quantile-quantile (QQ) plots. The left and right QQ-plot compare sample RT quantiles with normal and lognormal distributions.

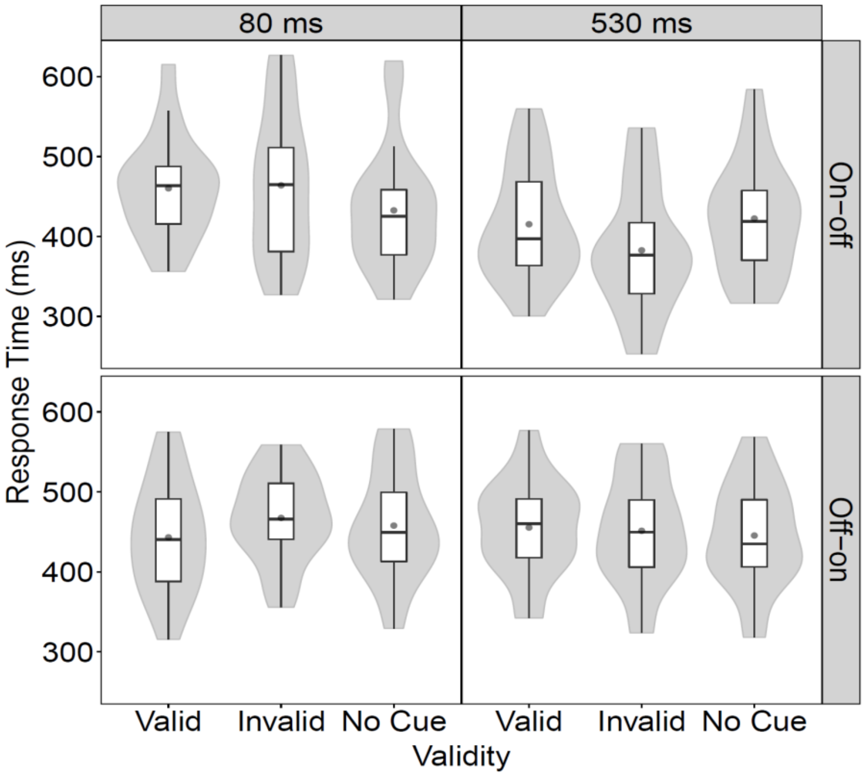


Figure 3.5. Experiment 2. Violin plots of raw reaction times. The violin plots from left to right show mean values for the conditions with SOA of 100 and 800 ms. Mean RTs (ms) are presented as boxplots. The graphs from top to bottom present mean values for the conditions with small and big stimuli. The lower and upper hinges correspond to the 25th and 75th percentiles. The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black points represent means. The violin plot outlines show kernel probability densities.

Descriptive Statistics for Error Rates

Participants committed false alarms in .04% of the target-absent catch trials. In target-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 0.81%, failed to respond within 1000 ms (“too late”) on 0.73% of the trials and pressed key within 150 ms on 0.16%. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 3.6 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 3.6 will not add up to the overall error rate.

GLMM on Reaction Times

The following analysis was conducted on the RTs in each trial.

I compared various models, increasing model complexity in terms of random effects stepwise (see Model M1 to M5 in Table 3.1). I always included Cue Type, SOA, Validity, and their interactions as fixed effects. Subjects served as a random factor in all models. Model 1 served as the simplest model because it includes a random intercept for each subject only. This model takes into account that participants may vary in their average response times. Model 2, 3, 4 and 5 have additional random slopes to model subject-specific effects of Cue Type, SOA, both of Cue Type and SOA, and all of Cue Type, SOA and Validity, respectively. The inclusion of random slopes relaxes the assumption that the fixed effect of Cue Type or/ and SOA or/ and Validity is the same across participants. A model comparison in terms of AIC, BIC and log-likelihood ratio test is summarized in Table 3.1.

Table 3.1

Model comparison of models with increasingly complex random-effects structures (*df*: the number of parameters in the model, related to the fixed and random effects of the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood ratio test between two successive models)

Models	*df*	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*-value
M1: RT ~ Cue Type * SOA * Validity + (1 | s)	14	110950	111050	-55461			
M2: RT ~ Cue Type * SOA * Validity + (1 + Cue Type | s)	16	110688	110802	-55328	265.845	2	$\ll 0.0001$
M3: RT ~ Cue Type * SOA * Validity + (1 + SOA | s)	16	110928	111043	-55448	0	0	1
M4: RT ~ Cue Type * SOA * Validity + (1 + Cue Type + SOA | s)	19	110665	110801	-55314	269.376	3	$\ll 0.0001$
M5: RT ~ Cue Type * SOA * Validity + (1 + Cue Type + SOA + Validity | s)	28	110605	110805	-55274	78.558	9	$\ll 0.0001$

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between estimates (absolute values less than 0.38). Model 5 had the lowest AIC (Akaike Information Criterion) and the second lowest BIC whereas Model 4 had the second lowest AIC but lowest BIC (4 points more than the lowest BIC, Bayesian Information Criterion). Both models are the most parsimonious model among the models tested. The results of Model 5 are reported here because it includes the by-subject random intercepts and by-subject random slopes for Cue Type, SOA and Validity.

Fixed Effects of RTs

A significant main effect of Cue Type was found, χ^2 (1) = 20.05, *p* < .001, for responses to off-on trials were on average 23 ms slower than on-off trials. A significant main effect of SOA was found, χ^2 (1) = 63.58, *p* < .001, for responses to trials with 80 ms SOA were on average 26 ms slower than trials with 530 ms SOA.

A statistically significant interaction between the Cue Type and SOA was found, χ^2 (1) = 144.02, *p* < .001. This interaction was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to trials of the on-off condition with 530 ms SOA were 46 ms faster than trials of the on-off condition with 80 ms SOA (*p* < .001), 49 ms faster than trials of the off-on condition with 80 ms SOA (*p* < .001), and 43 ms faster than trials of the off-on condition with 530 ms SOA (*p* < .001).

A statistically significant interaction between the Cue Type and Validity was found, χ^2 (1) = 56.57, *p* < .001. This interaction was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results revealed responses to trials of the on-off and valid condition were 15 ms slower than trials of the on-off and invalid condition (*p* = .003), and 23 ms faster than trials of the off-on and invalid condition (*p* = .004); responses to trials of the off-on and valid condition were 24 ms slower than trials of the on-off and invalid condition (*p* = .003), and 14 ms faster than trials of the off-on and invalid condition (*p* = .01); responses to trials of the on-off and invalid condition were 38 ms faster than trials of the on-off and invalid condition (*p* < .001), and 29 ms faster than trials of the off-on and no-cue condition (*p* = .001); responses to trials of the on-off and no-cue condition were 31 ms faster than trials of on-off and invalid condition (*p* < .001), and 22 ms faster than trials of off-on and no-cue condition (*p* = .002).

A statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 90.99, *p* < .001. This interaction was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to trials in the valid condition with 80 ms SOA were 15 ms faster than in the invalid condition with 80 ms SOA (*p* = .01), 17 ms slower than trials of the valid condition with 530 ms SOA (*p* < .001), and 33 ms slower than trials of the invalid condition with 530 ms SOA (*p* < .001); responses to trials in the invalid condition with 80 ms SOA were 19 ms slower than in the no-cue condition with 80 ms SOA (*p* = .001), 48 ms slower than trials of the invalid condition with 530 ms SOA (*p* < .001), and 31 ms slower than trials of no-cue condition with 530 ms SOA (*p* < .001);

responses to trials in the no-cue condition with 80 ms SOA were 29 ms slower than in the invalid condition with 530 ms SOA (*p* < .001), and 12 ms slower than in the no-cue condition with 530 ms SOA (*p* = .04); responses to trials in the valid condition with 530 ms SOA were 32 ms faster than in the invalid condition with 80 ms SOA (*p* < .001), and 16 ms slower than trials of the invalid condition with 530 ms SOA (*p* = .002); responses to trials in the invalid condition with 530 ms SOA were 17 ms faster than trials of the no-cue condition with 530 ms SOA (*p* = .01);

A statistically significant three-way interaction between the Cue Type, SOA and Validity was also found, χ^2 (1) =80.33, *p* < .001. I investigated this interaction by contrasts (χ^2 Test, *p*-value adjusted after Bonferroni). Firstly, I tested whether there were any facilitation in trials with 80 ms SOA and IOR in trials with 530 ms SOA. The results showed that in the on-off condition, responses to valid trials were nearly the same as invalid trials with 80 ms SOA, while responses to invalid trials with 530 ms SOA were 29 ms faster than valid trials with the same SOA (*p* < .001); in the off-on condition, responses to valid trials were 30 ms faster than invalid trials with 80 ms SOA (*p* < .001), but responses to invalid trials with 530 ms SOA were 2 ms faster than valid trials with the same SOA. Secondly, whether responses to no-cue trials were between responses to valid and invalid trials with either short (80 ms) and long (530 ms) SOA. The results showed that in the on-off condition, with 80 ms SOA responses to no-cue trials were 27 ms faster than valid trials (*p* < .001) and 27 ms faster than invalid trials (*p* < .001); with 530 ms SOA responses to no-cue trials were 11 ms slower than valid trials (*p* = 0.33) and 40 ms slower than invalid trials (*p* < .001). In the off-on condition, with 80 ms SOA responses to no-cue trials were 19 ms slower than valid trials (*p* = .004) and 11 ms faster than invalid trials (*p* = 0.58); with 530 ms SOA responses to no-cue trials were 9 ms faster than valid trials (*p* > 0.99) and 7 ms faster than invalid trials (*p* > 0.99), see Figure 3.6.

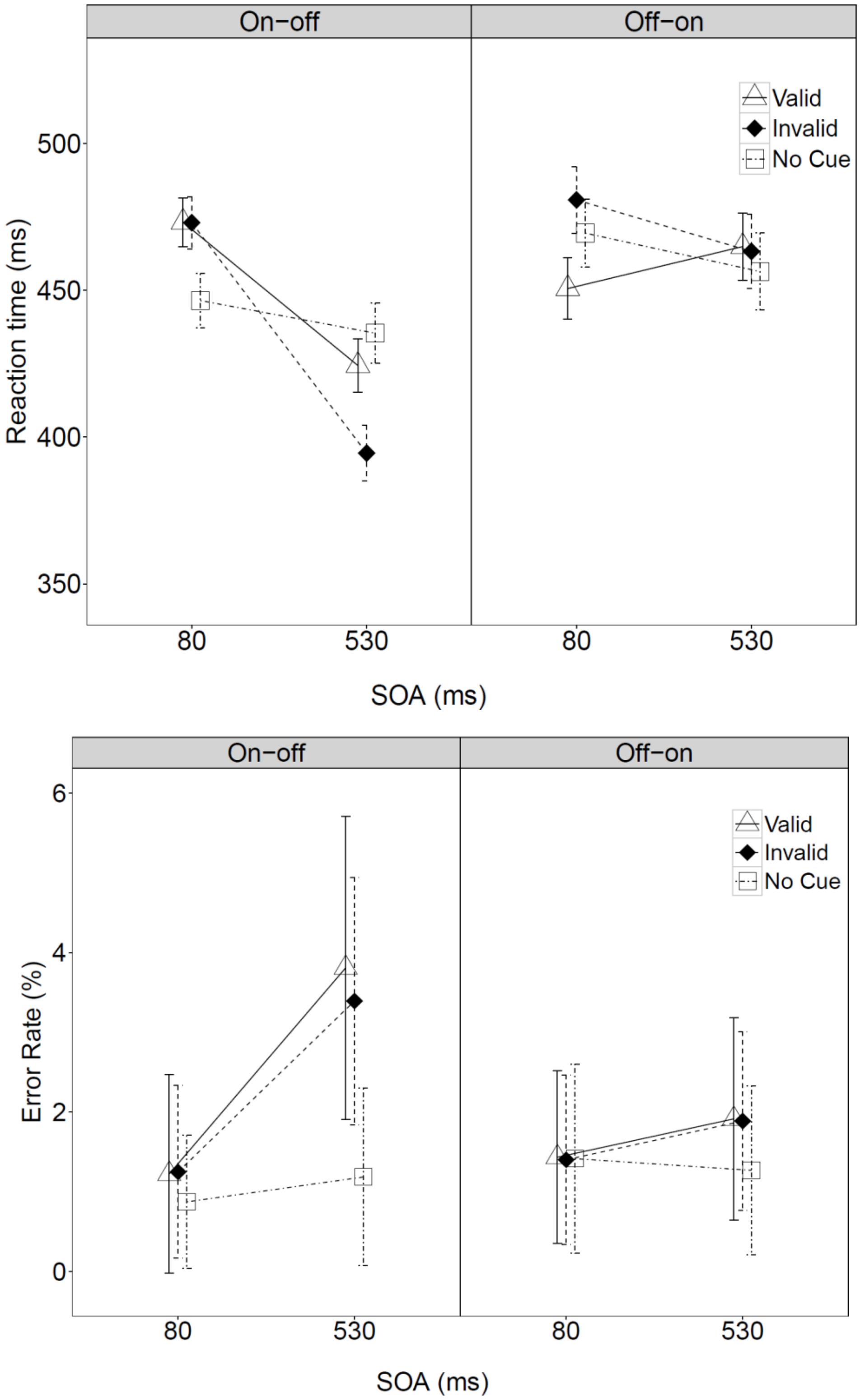


Figure 3.6. The line graph on the top panel shows adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 5, in Experiment 2. Error bars represent the 95% confidence intervals of the adjusted means.

Random Effects for RTs

Based on the model estimates, the individual variability of both intercept, Cue Type, SOA and Validity was computed. Figure 3.7 shows the conditional modes of the 20 participants, sorted by their intercept. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects.

The results suggested that individual differences were more prominent for Intercepts (*SD* = 21.81) than for slopes for Cue Type (on-off, *SD* = 9.07), SOA (80 ms, *SD* = 4.16), Validity (valid, *SD* = 5.79) and Validity (invalid, *SD* = 7.79), indicating that the individual variability in overall response times explained more variance than the individual variability of the effect of in the on-off condition, 80 ms SOA, valid and invalid condition. This is obviously shown in Figure 3.7, compared to all slopes, for the overall performances of individuals there are more participants whose confidence intervals do not touch the vertical line at zero (which represents group mean for intercepts and the mean of the fixed effect for slopes), deviating from the grand mean in further extents.

Figure 3.7 shows that participants varied in their mean RTs (Intercepts) from the grand mean, shown as the vertical line centred on zero in the plot on top in Figure 3.7 (Intercept). Participant 16 had the slowest mean RT, deviating the most to the right from the zero line, while Participant 3 had the fastest mean RT, deviating the most to the left. Only Participant 9 had nearly the same mean RT as the grand mean of 452.76 ms, with the horizontal error bar intersecting the vertical line at zero. Individual differences in on-off, valid and invalid were less pronounced as most of the individual estimates were scattered around the corresponding fixed effects in each plot (vertical lines centred at zero). Individual differences were least prominent in the effect of SOA 80 ms. These showed that participants' random effects for Cue Type, SOA and Validity were to a certain extent similar to each other.

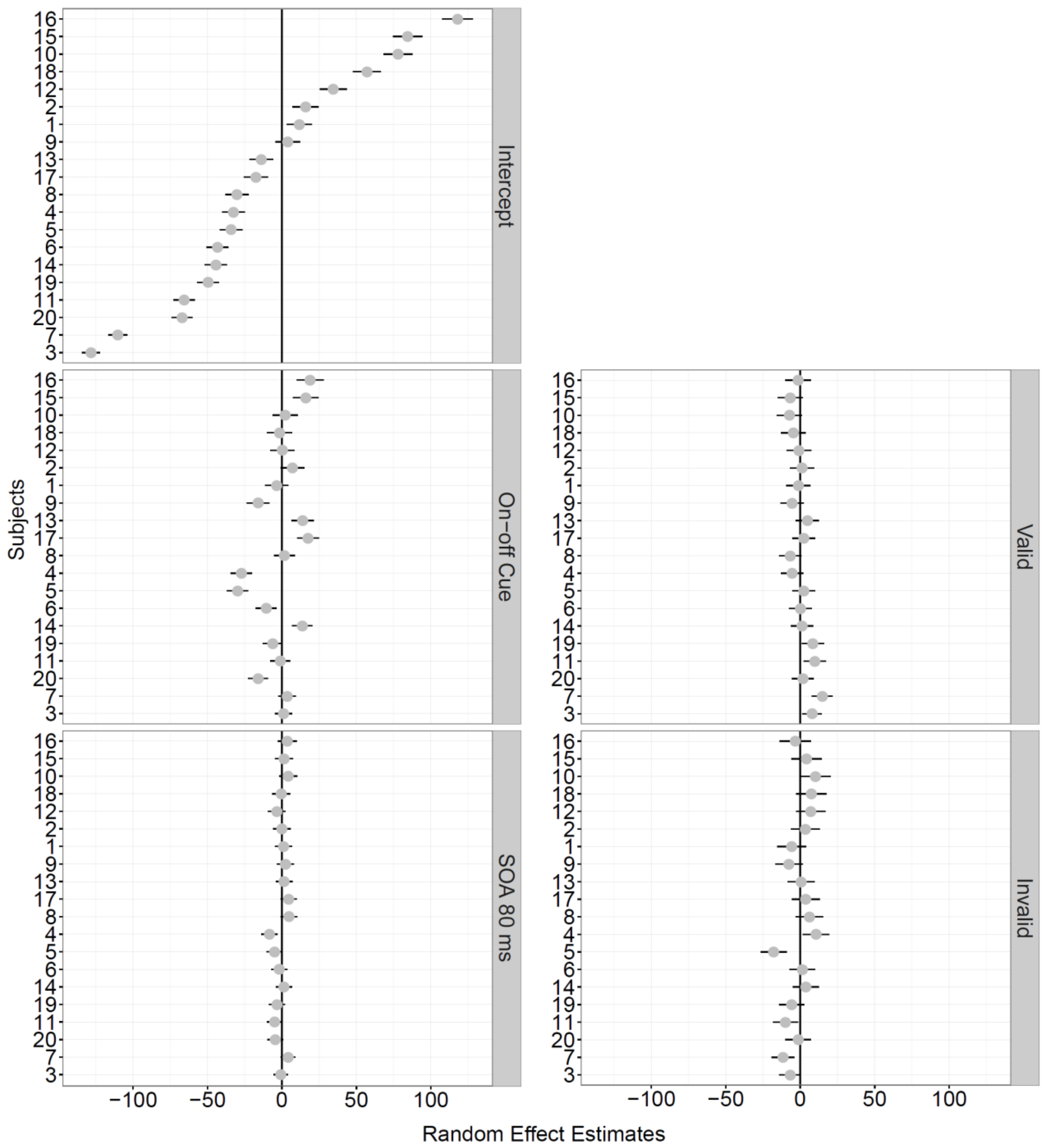


Figure 3.7. Visualization of the variance across subjects. Results of Experiment on 2 Random effects. Dotplots of random effects for each participant. The dotplots on the left panel from top to bottom show individual estimates of random intercepts and slopes for Cue Type, and SOA, anchored on on-off conditions and SOA 80 ms, respectively. The dotplots on the right panel from top to bottom show individual estimates of slopes for Validity, anchored on valid and invalid conditions, respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 80 ms was calculated by comparing the mean of the SOA 80 ms against the overall mean of the SOA.The vertical lines centred on 0 represent the group mean (452.76 ms) in the first panel and corresponding fixed effect estimates in the other plots, -11.54 for the on-off cue, 12.91 ms for SOA 80 ms, 0.57 ms for the valid condition, 0.20 for the invalid condition. Each dot represents a conditional mean and each horizontal error bar represents the corresponding 95% confidence interval. Participants are rank-ordered by their random intercept. In short, the dotplots show that the individual variability in overall response times explained more variance than the

other random slopes. Therefore, the individual variability in overall response times were far more prominent than the other random slopes.

3.4 Discussion

Evidence from the peripheral cueing paradigm showed that offset cues are able to capture attention (Posner & Cohen, 1984; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998) and that the attentional system treats offset cues similarly to onset cues (Birmingham and Pratt, 2005; Posner & Cohen, 1984; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998). However, onset and offset cues are treated differently when they appear in the same trial, as priority for attentional resources is given by the attentional system to onset cues over offset cues (Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001). Furthermore, evidence from studies by Riggio et al. (1998) using on-off cues indicated that, when onset and offset cues appear at the same location successively, there are interactions between them. The amount of inhibition was greater for on-off cues than for the sum of the separate IORs generated by onset and offset cues. There appeared to be an interaction between onset and offset cues when they appeared at the same location successively. Riggio et al. (1998) speculated that, for these two IORs to occur, there could be a common neural substrate where they are processed jointly and can strengthen each other. One question of interest is whether the interaction between onset and offset cues will be affected by the sequence of onset and offset cues. Do off-on cues have the same effect on facilitation and IOR as on-off cues? The present results indicate further how the attentional system treats onset and offset cues in a reversed sequence. In addition, I tested a condition with no cue to better identify the effects of on-off and off-on cues.

I found no facilitation for on-off cues, but did find facilitation for off-on cues for a short SOA of 80 ms. However, the results for IOR with a long SOA of 530 ms pointed in the opposite direction: I observed IOR for on-off cues, but observed no IOR for off-on cues for the long SOA. By comparing reaction times in the conditions of no cues and preceding cues, it is easy to know the effects of on-off and off-on cues on response times and how these effects lead to the presence of facilitation and inhibition for different types of cues.

The random effects of GLMM revealed that the individual variability in overall response times were far more prominent than the other random slopes, as shown by the dotplots. The random effect of GLMM explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals.

3.4.1 Effects of On-off Cues

Shortly after its presentation, the on-off cue affected responses to targets appearing at either side, no matter whether it preceded the target or not. More specifically, the onset of on-off cues caused a delay in responses compared to the no-cue condition. In this sense, the on-off cue had no benefit for target detection, but caused interference instead. As there were no statistically significant differences between response times to the valid and invalid conditions, no significant facilitation effect was observed for the short SOA, which is a similar finding to the studies using peripheral on-off cues (e.g., Colzato, Pratt, & Hommel, 2012; McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001; but see Bayliss, di Pellegrino, & Tipper, 2005). However, for the long SOA, the delay disappeared as responses to both the valid and invalid conditions were no longer slower than the responses to the no-cue condition. More specifically, for the cue location, the effect of cues appeared to fade out as responses to the valid and no-cue conditions were similar. If the target location was not preceded by the cue, the earlier delay later turned into a faster response as responses in the invalid condition were faster than in the no-cue condition. Responses in the invalid condition were also faster than in the valid condition, confirming the presence of IOR, as observed in previous studies using onset cues (Birmingham & Pratt, 2005; Posner and Cohen, 1984; Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994), offset cues (Birmingham & Pratt, 2005; Posner & Cohen, 1984; Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998), and on-off cues (Bayliss, di Pellegrino, & Tipper, 2005; Birmingham & Pratt, 2005; Riggio, Bello, & Umilta, 1998). In this case, the IOR is not caused by inhibition to the previously attended location (Posner, Rafal, Choate, & Vaughan, 1985), but rather by a bias toward the new location (McCarley et al., 2003).

3.4.2 Effects of Off-on Cues

Shortly after its presentation, the off-on cue, unlike the on-off cue, did not delay target detection as responses in the invalid condition were similar to responses in the no-cue condition. In addition, responses in the valid condition were faster than in the no-cue condition, which suggests that the cue benefitted target detection at the cue location. This benefit was the facilitation effect. In this sense, the off-on cue is able to capture attention shortly after its presence in the same way as an onset cue (Posner & Cohen, 1984; Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998) and an offset cue (Posner & Cohen, 1984; Pratt & McAuliffe, 2001; Riggio, Bello, & Umilta, 1998), and on-off cues (e.g., Bayliss, di Pellegrino, & Tipper, 2005). However, after a long time interval following the presence of off-on cues, the early benefits brought by these cues disappeared as responses to the valid condition were similar to responses to the no-cue condition. However, since responses to the invalid and no-cue conditions were statistically similar, unlike on-off cues, off-on cues brought no benefit to the location without preceding cues. Thus, IOR was not observed for longer SOAs.

These comparisons between the conditions of no cue and preceding cues suggest that the sequence within grouped onset and offset cues plays a role in the effects of grouped cues. Compared to the effects of on-off cues, the effects of off-on cues are more short-lived. Nevertheless, the short-lived effects of off-on cues are able to capture attention.

3.4.3 Cue-target Discriminability

Alternatively, the effects observed in this experiment may be explained by cue-target discriminability. When cues and targets have a similar visual appearance, facilitation is absent (McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001). For the on-off cues, the cue and target were closely matched in visual appearance as they had the same shape, size and luminance. When a peripheral stimulus appeared, it was straightforward to make a response if it was a green circle (i.e., a target). However, if it was a red circle (i.e., a cue), participants would refrain from responding. If a target appeared shortly after the cue onset, when it was still the refraining period, responses would be slower compared to the no-cue condition, in which straightforward responses were made. However, the process of refraining from making responses faded out over time and thus general target detection speeded up over time, which is indicated by the result that responses to targets which were preceded by cues for the long SOA were faster compared to responses to targets which were preceded by cues for the short SOA. It is possible that, shortly after the cue onset, on-off cues actually facilitated target detection at the cue location in the same way as off-on cues; however, facilitation was probably masked by the process of participants' refraining from making responses. Similarly, IOR might not be observed if the process of refraining from making responses did not fade out. For off-on cues, as the discriminability between cues and targets was more obvious, either a weaker or no such process of refraining from making responses took place. Therefore, without being masked, facilitation were observed at the cue location shortly after cue onset.

Chapter 4 The Effect of Size in Static and Dynamic Stimuli

4.1 Introduction

The shift of spatial attention triggered to the attended location by abrupt changes in the visual field enhances the processing of sensory information at the attended location, leading to faster response times and greater accuracy (e.g., Berger, Henik, & Rafal, 2005; Carrasco, Ling, & Read, 2004; Cheal & Lyon, 1991). The exogenous shift of attention is similar to a reflexive response (Giordano, McElree, & Carrasco, 2009; Yeshurun, Montagna, & Carrasco, 2008) which can be swiftly executed after the presence of stimulus which causes orientation (Cheal & Lyon, 1991). Exogenous cues are difficult to ignore even when these cues are not predictive of locations of upcoming targets (Awh, Matsukura, & Serences, 2003; Jonides, 1981). Exogenous attention enhances performance at the attended location, leading to greater acuity by improving the spatial resolution of stimuli (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Ling & Carrasco, 2006; Pestilli & Carrasco, 2005; Yeshurun et al., 2008).

Different accounts of attention have been proposed. Among them, the zoom-lens model, proposed by Eriksen and colleagues (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), suggests that the attended region can vary in size. This indicates the flexibility of the size of the attention field. They proposed that visual attention is a system with limited resources. The smaller the attentional window, the denser the processing resources which can be concentrated there, and the higher the processing efficiency of stimuli. Evidence from a neuroimaging study supports this view: While the activated regions of the visual cortex increased in correspondence with the size of the attended region, the level of neural activity in a given cortical subregion decreased (Müller, Bartelt, Donner, Villringer, & Brandt, 2003).

In previous studies, the size of the attentional region has been manipulated in two ways: By changing the spatial uncertainty of the target location (e.g., Huang, Xue, Wang, & Chen, 2016) and by varying the size of the cue (e.g., Burnett, d'Avossa, & Sapir, 2013). In studies that manipulated the attentional region by changing spatial uncertainty, varying numbers of cues were used to indicate the possible locations of targets (e.g., Müller, Bartelt, Donner, Villringer, & Brandt, 2003). Evidence from a neuroimaging experiment showed that the size of the attended region was larger with than without spatial uncertainty (Herrmann, Montaser-Kouhsari, Carrasco, & Heeger, 2010). Eriksen and St James (1986), who proposed the zoom-lens model, also provided evidence that reducing the number of adjacent locations which were cued at the same time resulted in faster responses.

In studies where the possible locations of upcoming targets were indicated by spatial cues of different sizes, a positive relationship was found between cue size and reaction times for target detection (Benso, Turatto, Mascetti, & Umiltà, 1998; Castiello & Umiltà, 1990; Maringelli & Umiltà, 1998; Turatto, et al., 2000). The effect in which changing cue size adjusts spatial attention has been termed the “cue size effect” (Mascetti, & Umiltà, 1998). Later, it was reported that the cue size effect could be affected by experimental design and cue-target stimulus onset asynchrony (Panagopoulos, von Grünau, Galera, Ivan, & Cavallet, 2006).

Previous studies investigated the cue size effect in exogenous attention by using either small or large cues to trigger attentional orienting toward the periphery. In the studies by Jiang et al. (2016), small and large cues were presented with illusion induced by depth cues on either a two-dimensional (2-D) or a three-dimensional (3-D) scene. In Experiment 1, in which the retinal sizes of cues were different but the perceived sizes were constant, responses to targets preceded by cues of smaller retinal size were facilitated compared to responses to cues of larger retinal size. The facilitatory effects were comparable between 2-D and 3-D displays. Furthermore, in Experiment 3, in which the depth background was removed, Jiang et al. (2016) still found facilitatory effects for small cues compared to large cues. This result indicates that, without the depth background, the different retinal sizes still affected the orientation of attention. Taken together, these results suggest that the retinal size of the cue plays an important role in the orientation of visual spatial attention. This result was confirmed in a simple detection task (Turatto, et al., 2000), in which responses were faster for targets that were preceded by small cues compared to targets preceded by large cues.

The studies about exogenous attention mentioned above make a direct comparison between the performance of responses to target preceded by cues with different sizes. Other studies have looked into the cue size effect on the difference between the performance of target detection when preceded and when not preceded by cues. In other words, they tested for an interaction between cue size and cue validity, i.e., whether or not the cue and target appear at the same location. In the studies by Burnett, d’Avossa, and Sapir (2013) a dual task was used, and the performance of target localisation was enhanced at the cue location compared to the other location, but only for small cues and not large cues. This evidence indicated that small-sized cues made better use of the limited resources in the periphery shared by the dual task, that is, two tasks which run at the same time.

Unlike the dual task, in a simple detection task which included only two locations, performance in target detection when cues preceded by cues (i.e., the valid condition) was always better compared to performance in target detection when cues was not preceded by cues (i.e., the invalid condition) for both small and large cues (Castiello & Umiltà, 1990). However, the benefits of cues for the valid condition compared to the invalid condition were stronger for the larger cue with the short SOA (40 ms) and were stronger for two smaller cues with the long SOA (500 ms). These indicated that the cue size not only interacted with validity, but also with SOA, as reported by Panagopoulos et al. (2006). Castiello & Umiltà (1990) used peripheral informative cues, in a task in which 80% of targets appeared at the same location as the informative cues. A question of interest is whether the interaction of size with validity and SOA could be found for peripheral non-informative cues. Posner and Cohen (1984) used a peripheral exogenous cueing paradigm to investigate the orientation of attention, and found facilitation for short SOA and IOR for long SOA, which are the results of the interaction between validity and SOA. The question of whether the interaction of size with validity and SOA could be found for non-informative cues leaded to the question that whether stimulus size modulates facilitation and IOR for non-informative cues in the periphery.

In this experiment, the size of the stimuli have two levels of variation, small and large. I used the size of stimuli in the studies where peripheral non-informative cues were used and where both facilitation and IOR were found. The size of the small stimuli was adopted from the studies by Posner and Cohen (1984) and the size of the large stimuli was from the studies by Bayliss et al. (2005). I hypothesised facilitation should increase for small stimuli compared to large stimuli. However, since the evidence showed that IOR is not affected by physical characteristics (Pratt, Hillis, & Gold, 2001; also see Experiment 1), I hypothesised that IOR should not be affected by the stimulus size.

4.2 Experiment 3A

This experiment aims to investigate whether stimulus size modulates facilitation and IOR. The size of the small stimuli was adopted from the studies by Posner and Cohen (1984) and the size of large stimuli was from Bayliss et al. (2005). First, I hypothesise that general response times across all conditions for stimuli of small size should be faster than large size; second, the magnitude of facilitation should be larger for the small size compared to large size; third, IOR should not be affected by the stimuli size, as there is evidence to suggest that

IOR is not affected by physical characteristics (Pratt, Hillis, & Gold, 2001; also Experiment 1).

4.2.1 Method

Participants

A total of *N* = 16 students from the University of Glasgow, aged from 18 to 30 and with normal or corrected-to-normal vision, participated in this experiment. All the participants were naive to the purpose of the experiment. This study received ethical approval from the Review Board of the College of Social Sciences, University of Glasgow. Written informed consent was obtained from all participants and they received £3 for their participation.

Apparatus and materials

Stimuli were shown on a colour BenQ LCD computer monitor (24 inches). All stimuli were shown in white on a black background (see Figure 4.1). The fixation point extended 2° at a viewing distance of 78 cm. The fixation cross consisted of two crossed straight lines (0.07° thick), and was presented at the centre of the screen. Two placeholder boxes to the left and right of the fixation cross indicated the possible location of cues and targets. The cues were empty squares, fully covering the lines of placeholder boxes and targets were filled squares, appearing at the centre of the boxes in the periphery. Two sizes of stimuli were involved in the present experiment. In the set identical with sizes of stimuli of the study by Posner and Cohen (1984), cues and placeholder boxed subtended 1° and target 0.1°, while in the large-size set in line with Bayliss et al. (2005), cues were created by combining lines (0.6° thick), and placeholder boxes were measured 5.4° as well as target 0.9°. In the small-size set of stimuli, the line width of cues and placeholder boxes, not being mentioned in the study by Posner and Cohen (1984) study, were 0.1° and 0.04°, respectively. In the large-size set, the placeholder boxes were indicated by straight lines (0.07° thick). Same as Posner's (1984) study, all the cues, targets and placeholders boxes, from both sets, appeared 8° from the centre of screen; see Figure 4.1.

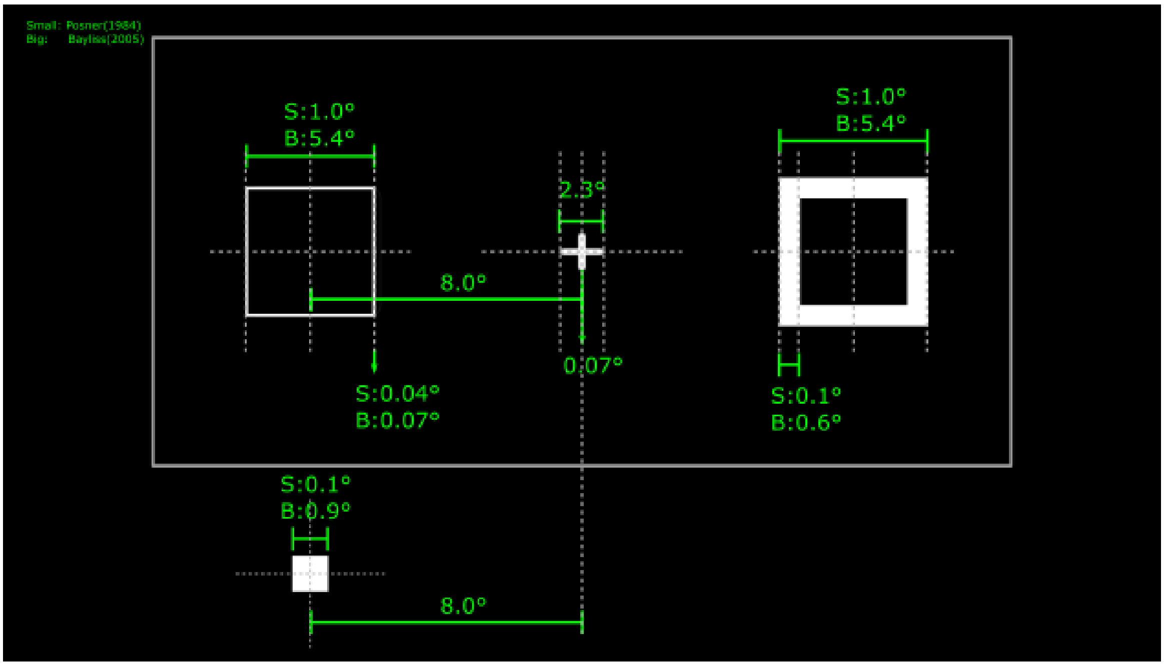


Figure 4.1. Illustration of stimulus presentation in Experiment 3A with visual angles. Within the large rectangle, from left to right are an example of placeholder, fixation point and cue. An example of the target is shown below the placeholder but was actually shown inside the placeholder.

Design

As in Experiment 1, there were three within-subject factors. The factor SOA and Validity were the same as in Experiment 1 while factor Novelty was replaced by factor Size (small; large); in each trial there was either a larger cue and target (large stimuli) or a smaller cue and target (small stimuli). The order of the stimulus size was counter-balanced across blocks and observers.

Procedure

The procedure was the same as in Experiment 1, except that the maximum response time (RT) was reduced to 500 ms. The reason for this reduction was that this detection task was simpler and therefore more straightforward to respond to. In a pilot study participants responded quicker if they were focused on the detection task at hand. Therefore trials with a RT exceeding 500 ms were considered as error trials because the participant was not sufficiently attentive. The experiment included two types of blocks, a block consisting of trials with large stimuli and a block composed of trials with small stimuli. First, participants had to complete four training blocks, two blocks with small stimuli alternated with two blocks with large stimuli. Participants only progressed to the next block after they completed

15 successive trials correctly, otherwise they had to complete a total of 30 trials. After the training session, there were eight blocks of trials, four with large stimuli and four with small stimuli arranged in an alternate order. Each block contained 40 trials with 8 (20%) catch trials. This experiment had 320 experimental trials (excluded training trials) in eight blocks. The timeline of a trial is illustrated in Fig. 4.2.

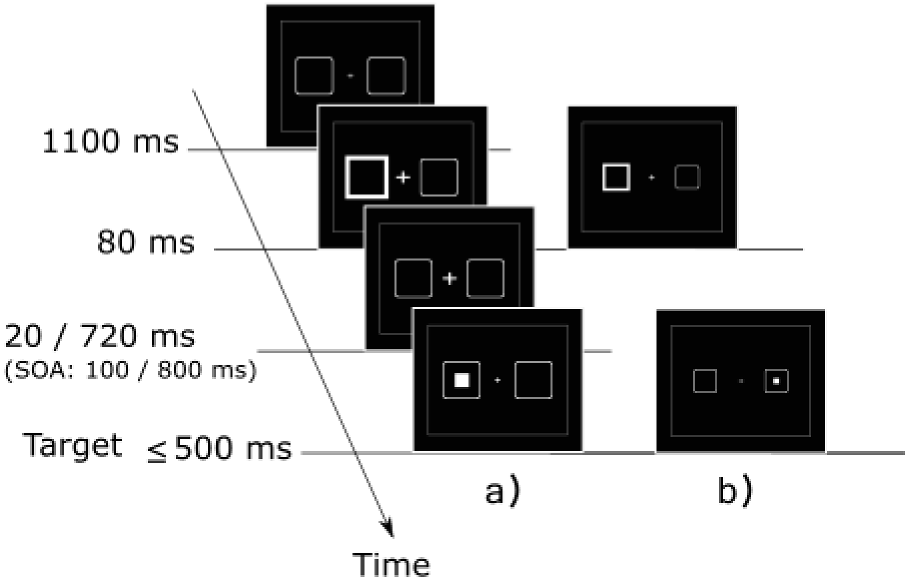


Figure 4.2. Time course of stimulus presentation in Experiment 3A. Column a) illustrates a valid trial, with large cue and target. Column b) illustrates an invalid trial, with a small cue and target.

Data Analyses

The approaches used in this experiment were the same as Experiment 2. I conducted GLMMs on RTs. Error trials and catch trials were excluded from the RT analyses.

4.2.2 Results

Descriptive Statistics of Reaction Times

As shown in the QQ plots (see Figure 4.3) and violin plots (see Figure 4.4), the distributions of single-trial raw RTs and in the current experiment were approximately normally distributed.

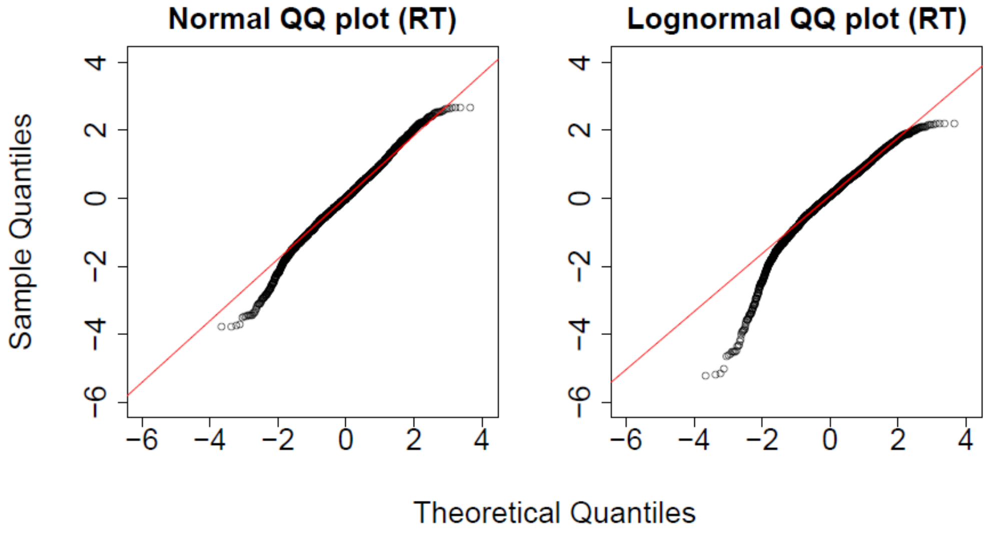


Figure 4.3. Experiment 3A. Quantile-quantile (QQ) plots. The left and right QQ-plot compare sample RT quantiles for normal and lognormal RT distributions.

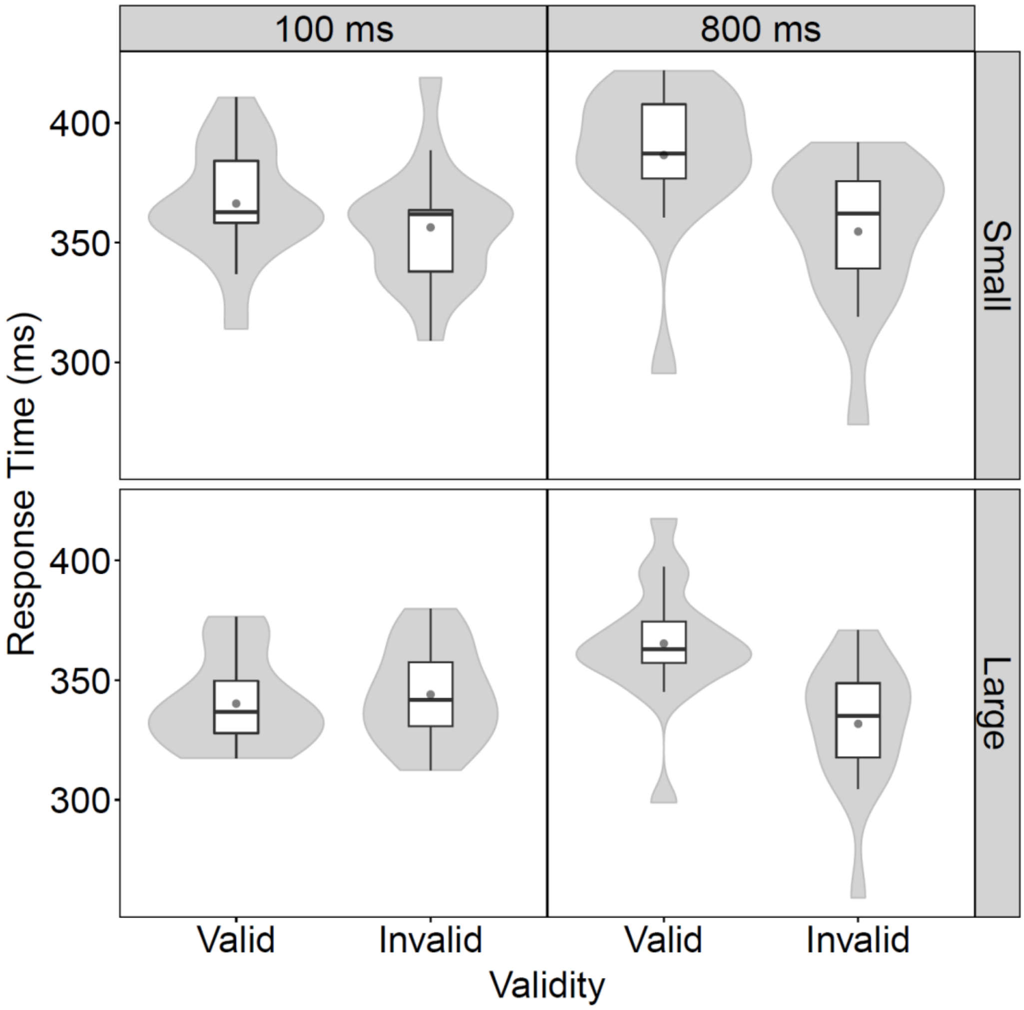


Figure 4.4. Experiment 3A. Violin plots of raw reaction times. The violin plots from left to right show mean values for the conditions with SOA of 100 and 800 ms. Mean RTs (ms) are presented as boxplots. The graphs from top to bottom present mean values for the conditions

with small and large stimuli. The lower and upper hinges correspond to the 25th and 75th percentiles. The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black points represent means. The violin plot outlines show kernel probability densities.

Descriptive Statistics for Error Rates

Participants committed false alarms in 0.39% of the target-absent catch trials. In stimuli-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 1.78%, failed to respond within 750 ms (“too late”) on 1.78% of the trials and pressed key within 150 ms on 0.47%. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 4.5 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 4.5 will not add up to the overall error rate.

GLMM on Reaction Times

The following analysis was conducted on the RTs in each trial.

I compared various models, increasing model complexity in terms of random effects stepwise (see Model M1 to M6 in Table 4.1). I always included the full factorial design of the experiment, that is, Size, SOA, Validity, and their interactions as fixed effects. Subjects served as a random factor in all models. Model 1 is the simplest model because it postulates a random intercept for each subject only. This model takes into account that participants may vary in their average response times. Model 2, 3, 4, 5 and 6 have additional random slopes to model subject-specific effects of Size, SOA, Validity (the relative location between the cue and target), both of Size and SOA, and both of SOA and Validity, respectively. The inclusion of random slopes relaxes the assumption that the fixed effect of Size or/ and SOA or/ and Validity is the same across participants. A model comparison in terms of AIC, BIC and log-likelihood ratio test (comparing the current with the previous model) is summarized in Table 4.1.

Table 4.1

Model comparison of models with increasingly complex random-effects structures (*df*: the number of parameters in the model, related to the number of estimated model parameters for fixed and random effects of models, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood ratio test between two successive models)

Models	*df*	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*-value
M1: RT ~ Size * SOA * Validity + (1 | s)	10	41440	41503	-20710			
M2: RT ~ Size * SOA * Validity + (1 + Size | s)	12	41425	41500	-20700	19.346	2	≪0.0001
M3: RT ~ Size * SOA * Validity + (1 + SOA | s)	12	41290	41365	-20633	135.381	0	≪0.0001
M4: RT ~ Size * SOA * Validity + (1 + Validity | s)	12	41432	41507	-20704	0	0	1
M5: RT ~ Size * SOA * Validity + (1 + Size + SOA | s)	15	41272	41366	-20621	166.088	3	≪0.0001
M6: RT ~ Size * SOA * Validity + (1 + SOA + Validity | s)	15	41283	41377	-20627	0	0	1

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between estimates ($r < 0.99$). Model 5 had the lowest BIC (Bayesian Information Criterion) and the second lowest AIC (only 1 point more than the lowest AIC, Akaike Information Criterion), and was selected as the most parsimonious model among the models tested. Model 5 includes by-subject random intercepts and by-subject random slopes for Size and SOA.

Fixed Effects of RTs

A significant main effect of Size was found, χ^2 (1) = 47.10, $p < .001$, for responses to small targets preceded by small cue were on average 21 ms slower than large targets preceded by large cues. A significant main effect of Validity was found, χ^2 (1) = 139.09, $p < .001$, with responses to trials in the valid condition were 19 ms slower than in the invalid condition. A statistically significant interaction between SOA and Validity was found, χ^2 (1) = 91.95, $p < .001$. This interaction was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results revealed responses to trials of valid condition with

800 ms SOA were 24 ms slower than trials of valid condition with 100 ms SOA ($p = .003$), 27 ms slower than trials of invalid condition with 100 ms SOA ($p < .001$), and 33 ms slower than trials of invalid condition with 800 ms SOA ($p < .001$). Moreover, a statistically significant interaction between the Size and Validity was found, χ^2 (1) = 4.33, $p = .04$, and was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that in the valid condition, responses with small stimuli were 24 ms slower than responses with large stimuli ($p <.001$), and in the invalid condition, responses with small stimuli were 18 ms slower than responses with large stimuli ($p <.001$). These indicated the size effect in both valid and invalid condition. A further test revealed that the size effect in the valid condition was 6 ms stronger than the size effect in the invalid condition ($p = 0.04$). Furthermore, the result that stronger size effect in the valid than invalid condition is found for the short SOA ($p = .002$) but not for the long SOA.

A statistically significant three-way interaction between the Size, SOA and Validity was also found, χ^2 (1) = 6.26, $p = .01$. I investigated this interaction by contrasts (χ^2 Test, *p*-value adjusted after Bonferroni). Firstly, I examined whether there were facilitation or IOR in the condition of each SOA and Size. The results showed that with small size stimuli, responses to invalid trials with 100 ms SOA were 10 ms faster than valid trials with the same SOA ($p = .003$), and responses to invalid trials with 800 ms SOA were 32 ms faster than valid trials with the same SOA ($p < .001$). With large stimulus size, responses to invalid trials with 100 ms SOA were 4 ms slower than valid trials with the same SOA ($p = .84$), and responses to invalid trials were 34 ms significantly faster than valid trials ($p < .001$). In short, I found no facilitation effects but IOR in conditions with both small and large size stimuli with 800 ms SOA, and even in the condition with 100 ms SOA when stimuli were small size. For the second contrast, I compared the IORs between levels of Size for the 800 ms SOA. Results revealed that there were no difference in IORs with small and large stimuli for the 800 ms SOA, see Figure 4.5.

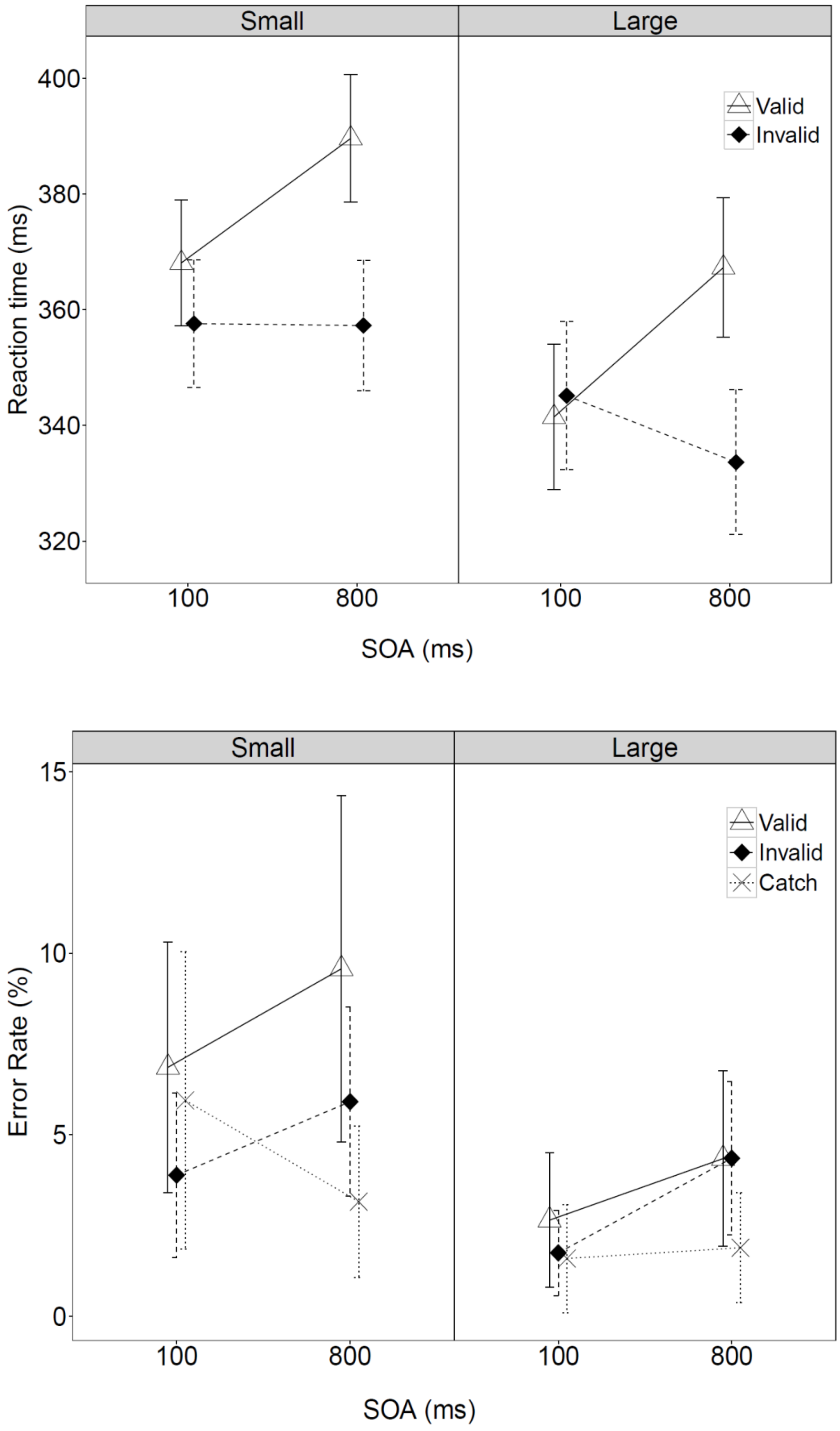


Figure 4.5. The line graph on the top panel shows the adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 5, in Experiment 3A. Error bars represent the 95% confidence intervals of the adjusted means. The line graph on the bottom panel shows the ERs (%) averaged across subjects of Experiment 3A. Error bars denote ±1.96 SEM.

Random Effects for RTs

Based on the model estimates, the individual variability of both intercept, Size and SOA was computed. Figure 4.6 shows the conditional modes of the 16 participants, sorted by their intercept. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects.

The results suggested that individual differences were more prominent for intercepts (*SD* =8.63) than for slope for stimulus size (small stimuli, *SD* = 2.89) and SOA (100 ms, *SD* =5.88), indicating that the individual variability in overall response times explained more variances than the individual variability of the effect of small-size stimulus size and SOA 100 ms. This is clearly shown in Figure 4.6, compared to 100 ms SOA, for the overall performances of individuals there are more participants whose confidence intervals do not touch the vertical line at zero (which represents the mean of the fixed effect), deviating from the grand mean in further extents. For example, the overall response time of Participant 11 was 50 ms faster compared to the other participants and Participant 9 was the slowest responder as his/ her average RT deviated most from the zero line to the right. Only Participant 6, 7, 1, and 13 were not significantly faster or slower than the overall performance, as their error bars of data points intersect with the zero line in the dotplot. Individual differences in SOA 100 ms were not as pronounced as the individual mean RTs with fewer deviations from the zero line (the fixed effect for SOA 100 ms, -4.44 ms). In addition, individual differences were least prominent in Size Small as most of the individual data points close to the zero lines (the fixed effect for Size Small, 10.63 ms).

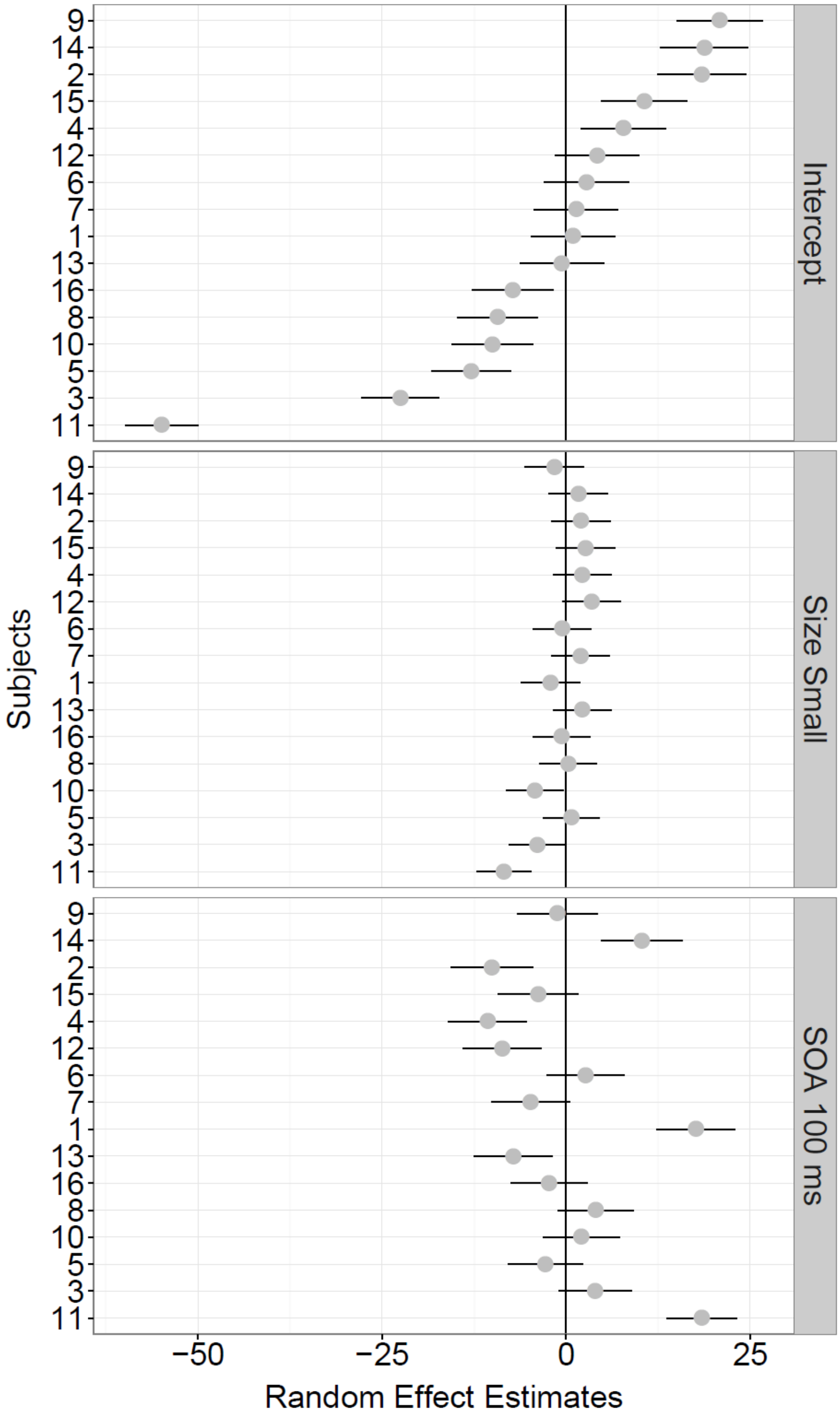


Figure 4.6. Visualization of the variance across subjects. Dotplots of random effects for each participant in Experiment 3A. The dotplots from top to bottom show individual estimates of random intercepts (top) and slopes for stimulus size Small (middle), and SOA 100 ms (bottom), respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 100 ms was calculated by comparing the mean of the SOA 100 ms against the overall mean of the SOA. The vertical lines centred on 0 represent the grand mean (357.52 ms) in the first panel and corresponding fixed effects estimates in the other two panels below, 10.63 ms for Size Small and -4.44 ms for SOA 100 ms. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. Participants are rank-ordered by their random intercepts. In short, the dotplots show that individual variability in overall response times explained more variances

than the other random slopes. Therefore, the individual variability in overall response times were far more prominent than the other random slopes.

4.2.3 Discussion

This experiment aimed to investigate the effects of size on facilitation and IOR. I hypothesised that facilitation should increase for small stimuli compared to large stimuli, but IOR should not be affected by stimulus size.

The results showed that performance for large stimuli was better than or small stimuli, in terms of both response times and error rates. The performance for small stimuli indicates a higher level of difficulty than for small stimuli. In addition, responses for large stimuli were faster than for small stimuli in both the valid and invalid condition. The effect of size is stronger in the valid condition than the invalid condition, that is, faster responses for large stimuli than small stimuli were found in both the valid and invalid conditions. In addition, the random effects of GLMM revealed that the individual variability in overall response times were far more prominent than the other random slopes, as shown by the dotplots. The random effect of GLMM explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals.

In terms of facilitation and IOR, no facilitation was observed for both sizes of stimuli, but IOR was observed instead with small stimuli for the short SOA. The absence of facilitation and early inhibition, although not predicted, is consistent with previous studies (e.g., Prime et al., 2006; Tassinari et al., 1994). Nevertheless, for long SOA, IOR was observed for both small and large stimuli. As predicted, a comparison of IORs between small and large stimuli revealed that the size of stimuli had no statistically significant influence on the magnitude of the IOR at long SOAs.

The zoom-lens model (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) predicts better performance for small stimuli than for large stimuli, and this was also found in a task where targets were always preceded by cues (e.g., Jiang et al., 2016; Turatto, et al., 2000). However, in tasks where targets may or may not be preceded by cues, the overall performances for small and large stimuli were similar in accuracy (e.g., Burnett, d'Avossa, & Sapir, 2013) and speed (e.g., Castiello & Umiltà, 1990). In Experiment 3A, however, the performance of target detection for small-sized stimuli was worse than for large-sized stimuli. This result is inconsistent with the findings of previous studies. It might be that the small stimuli in the present experiment made the task more difficult to perform compared to the large stimuli. This was also reported by participants after the experiment. In order to solve this problem in Experiment 3B, I used the same size of stimuli as Bayliss et al. (2005), which corresponds to the large stimulus size in Experiment 3A. In addition, for the horizontal separation of peripheral stimuli from the fixation, I used the same distance as in the studies by Bayliss et al. (2005), instead of the distance in the studies by Posner and Cohen (1984). Therefore in terms of visual angle, the experimental stimuli were presented in the same way as in Bayliss et al. (2005), who found facilitation for short SOAs.

4.3 Experiment 3B

4.3.1 Introduction

Turatto et al. (2000) examined whether the size of the attentional focus could be changed when another object with a different size was imposed onto the present cue, see Figure 4.7. Two conditions included the same object throughout one task. These two single-cue conditions included a small and a large circle, respectively. For the two double-cue conditions, one had a large square which appeared following a small circle, and the other had a small square which abruptly appeared following a large circle. The small and large circles in the dual-cue conditions had the same size as the small and large circles in the single-cue conditions, respectively. This manipulation by Turatto et al. (2000) allows us to examine whether the attentional focus will adjust its size when a later object of a different size is imposed onto the present object, or remain its original size. In the single-cue condition, they did find faster responses to targets preceded by the small cue, compared to targets preceded by the large cue. More importantly, for dual-cue conditions, even though participants were instructed to focus on only the first circle cue while ignoring the later cue, response times for target detection were affected by and following the cues appearing later, see Figure 4.8 for the results. These results suggest that the attentional focus adjusted in size when another cue abruptly appearing after the first cue.

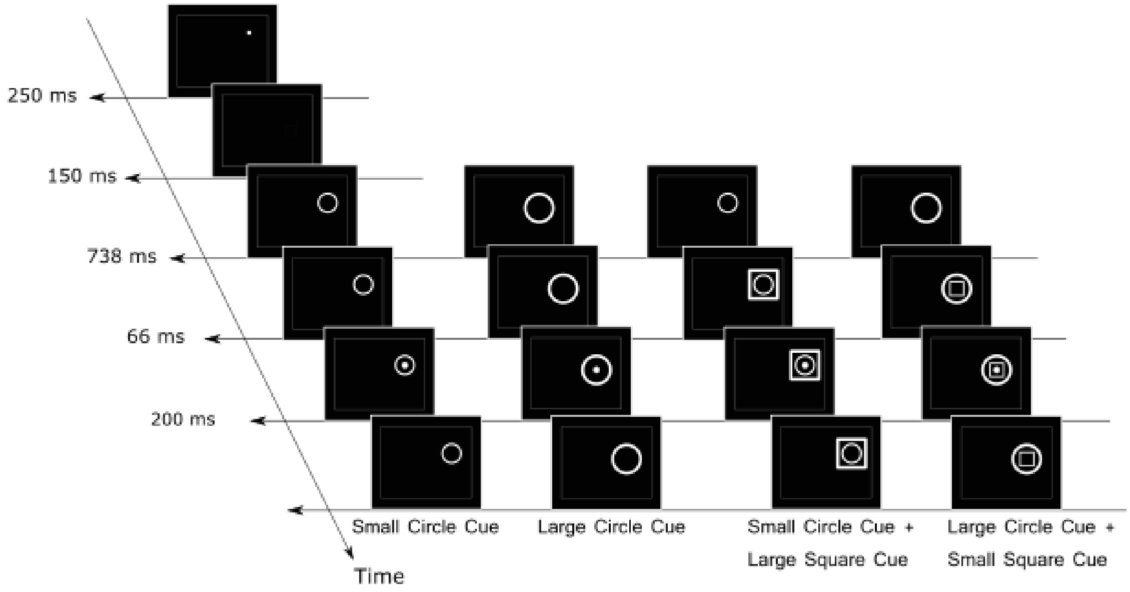


Figure 4.7. Illustration of the design of the Experiment 3 by Turatto et al. (2000).

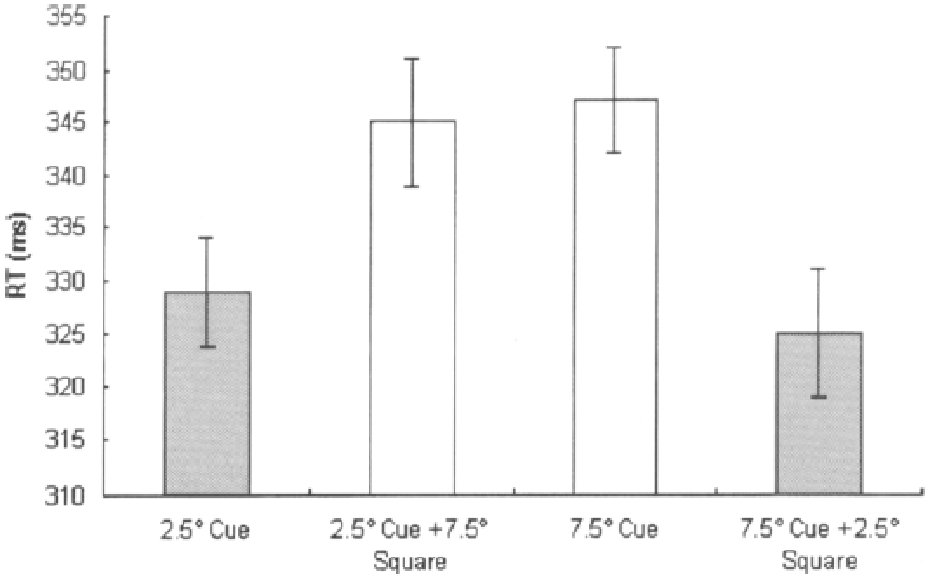


Figure 4.8. This figure is reproduced from Turatto et al. (2000), Fig. 5, p. 945. This figure is the illustration of the results of the Experiment 3 by Turatto et al. (2000).

The present experiment used apparent motion cues to further investigate the effects of changes in cue size on target detection. The motion cues either contracted or expanded in a dynamic process, which was presented by five successive cues with either an increase or a decrease in size. Motion cues may be regarded as an analogy to the dynamic process of adjusting the attentional “zoom lens”. In addition, motion stimuli can effectively capture attention even when the motion is uninformative to the task (e.g., Abrams & Christ, 2003; 2005; von Mühlenen & Lleras, 2007). Furthermore, uninformative motion cues, although endogenous, enhanced performance of target detection in the periphery when the target location was indicated by the motion cue (Shi, Weng, He, & Jiang, 2010). Taking these together, compared to static cues, the motion cues in this experiment should work more effectively in detecting peripheral stimuli preceded by uninformative cues. In this sense, the motion cue allows us to better examine the size effect of stimuli on the detection of peripheral stimuli preceded by uninformative cues. Static cues are included as controls, as in the single-cue conditions in the studies by Turatto et al. (2000).

I hypothesised that the magnitude of facilitation would be larger for the stimuli of small size compared to the stimuli of large size and would be larger for motion cues than static cues. However, as there is evidence to show that IOR is not affected by physical characteristics (Pratt, Hillis, & Gold, 2001; also see Experiments 1 & 3A of this thesis), I hypothesise that IOR would not be affected by stimuli size, either when the cue is static or when the cue is dynamic.

4.3.2 Methods

Participants

A total of *N* = 30 neurotypical students from the University of Glasgow (mean age = 23.9 years, *SD* = 3.1, 8 males, 22 female) participated in the experiment. All observers had normal or correct-to-normal visual acuity and were naive to the purpose of the experiment. The experiment adhered to BPS guidelines and was approved by the Ethics Committee of the College of Science and Engineering, University of Glasgow. Participants gave written consent and received £5 for taking part.

Stimuli and apparatus

Stimuli were displayed on a colour Dell LCD computer monitor (21 inches). The participant pressed the right button on a response box (Black Box Toolkit). The response box was served as the input device and was connected to a Dell PC in order to record RTs with high temporal resolution. The experiment was run in PsyToolkit, a software for programming psychological experiments and surveys on the Linux operating system (Stoet, 2010). Participants were seated 57 cm from the screen with their head positioned on a chin rest. All stimuli were presented in white on a black background (see Figure 4.9). The fixation cross subtended 3.4° at the centre of the screen and was composed of a vertical and horizontal line (0.1° wide). Cues were empty squares, displayed at 12º visual angle to the left and right of the fixation cross in the periphery. This experiment included two types of cue: the static cue and the motion cue. All the cues were all empty squares, composed of lines 1.1° in width. However, the sizes of the two types of cues were different. For motion cues, there were five sizes, which changed gradually. The visual angles of outlines of the square from the smallest one to the largest one were 5.6°, 6.7°, 7.8°, 8.9°, and 10.0°. For static cues, the small size cue was the same as the smallest square of the animated motion cues, whereas the largest sized cue was the same as the largest cue of the animated motion cues. The target was a filled white square measuring 0.9°. The target was centred on the same positions as the cues to the left and right of the fixation cross.

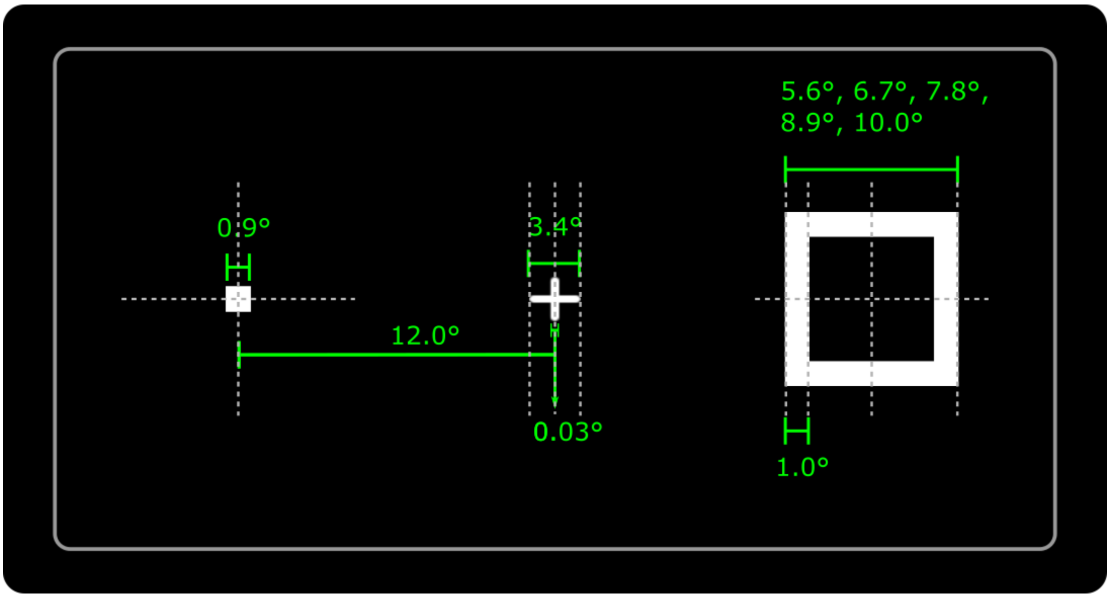


Figure 4.9. Experiment 3B. Illustration of the stimulus display. Visual angles in degrees are indicated in Green and were not visible during the stimulus display. Stimulus components from left to right are a target (filled square), the fixation cross at the centre and a cue (empty square).

Design

This experiment had a four-factorial within-subject design. The first factor was Cue Type including static and motion-cue conditions. In the static-cue condition, the target was preceded by a single cue presentation. However, in the motion-cue condition, the target was preceded by a motion cue using a frame-by-frame animation, composed of five successive displays with gradually increasing size (expanding condition) or decreasing size (contracting condition). The second factor was Size of cues. In the static-cue condition, Size was manipulated similar to Experiment 2, with small or large size. In the motion-cue condition, the cue was expanding or contracting. The third and fourth factor were standard factors in the Posner cueing paradigm for studying the effect of facilitation and IOR, namely, stimulus onset asynchrony (SOA) and Validity. The factor SOA, the interval between the onset of the cue and the target, had two levels of 150 and 850 ms. The factor Validity was defined by comparing the location of the cue and target. In valid trials, the target appeared at the same horizontal location in the periphery as the cue whereas in invalid trials, the target appeared at the opposite horizontal location in the periphery. All trial conditions appeared with equal probability. In addition, catch trials (20% of the trials) were divided equally between blocks and randomly interspersed within blocks. In a catch trial, a cue appeared at either location but without presenting the target afterwards. All trials were presented in randomized order.

Procedure

Participants received written instructions before the experiment. Each trial was initiated by showing a fixation cross that was displayed at the centre of the screen for 1100 ms (see Figure 4.10). Participants were instructed to maintain fixation on the cross throughout each trial and to respond to the target as fast and accurately as possible by pressing the response button regardless of the location of the target. Participants were instructed to ignore the cues and respond to the target only.

In the static-cue condition, a small or large cue appeared for 100 ms on the left or right of the screen, followed by a target at the same or opposite location after an interval of 50 ms or 750 ms (SOA 150 ms and 850 ms). In the motion-cue condition, an expanding or contracting motion cue was displayed. The first four frames were presented for 10 ms each and the last one for 60 ms. Either the static and motion cue was followed by an interval of 50 or 750 ms, resulting in combinations of SOA 150 ms and 850ms. The target appeared after the static or motion cue and remained on the screen until a response was made or 750 ms elapsed, whichever happened first (Figure 4.10). A correct detection response was instantly followed by positive feedback (“good”), while a late response after 750 ms in non-catch trials was followed by the error message “too slow”. When a response was detected at the onset of a cue and before the onset of a target as well as in a catch trial the error message “too early” would appear immediately. Error messages were presented for 3080 ms and correct messages for 300 ms in order to reward correct responses. Each response time (RT) was measured from the onset of the target to the button press. Twenty percent of trials of each block were catch trials, randomly intermixed between trials. Each participant completed a total of 988 trials over 14 blocks. For preventing the motion effect affect the processing of static cues, I blocked the trials with static cues and trials with motion cues. Therefore, half of the block consisted of trials with static cues only and the other half consisted of trials with motion cues only. The first two block were training blocks, each containing 14 training trials. Each of the remaining blocks consisted of 80 trials. In each block trials were randomly intermixed.

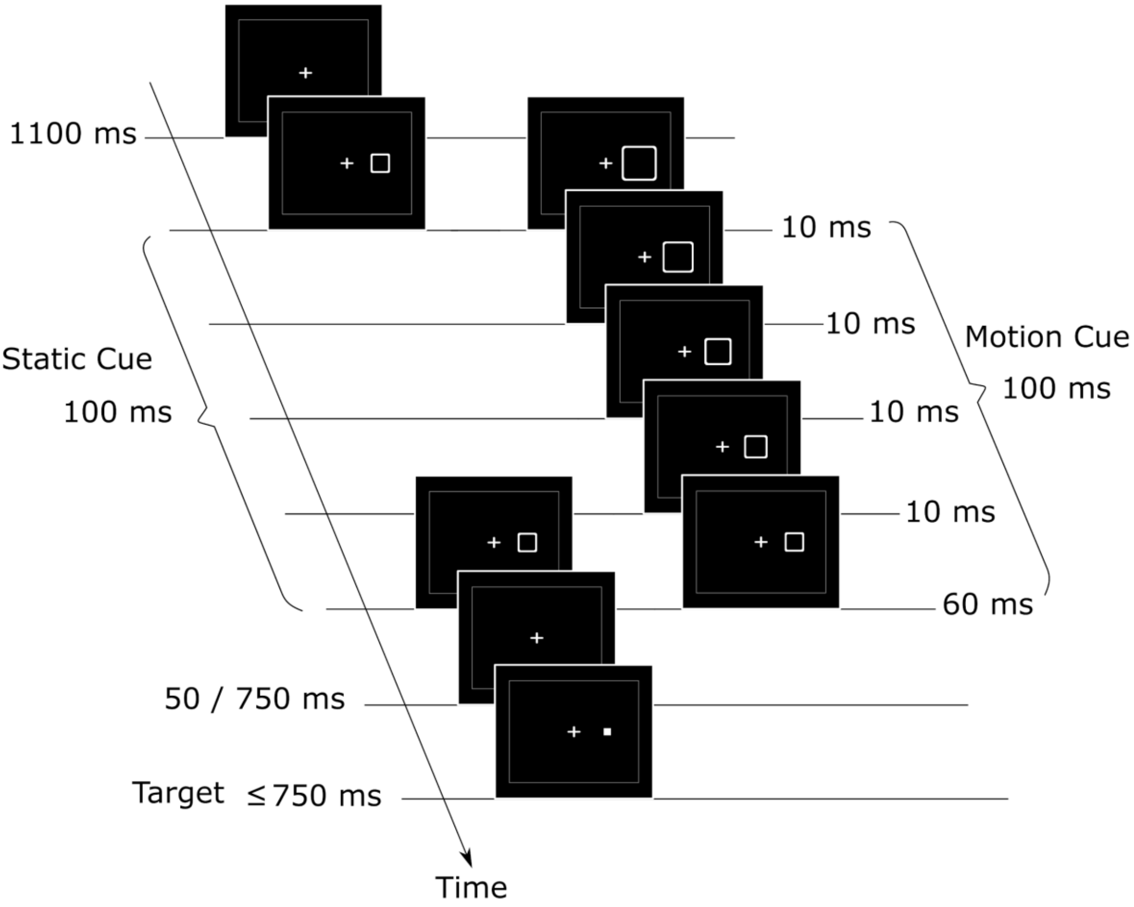


Figure 4.10. Illustration of time courses during stimulus presentation (a) in an invalid trial in the single-cue condition, (b) in an invalid trial in the motion condition.

Data Analyses

The approaches used in this experiment were the same as Experiment 2. I conducted GLMMs on RTs. Error trials and catch trials were excluded from the RT analyses.

4.3.3 Results

Descriptive Statistics of Reaction Times

As shown by the violin plots (see Figure 4.11) and QQ plots (see Figure 4.12), the distributions of single-trial raw RTs in the current experiment were skewed, violating the assumption of normality. I employed GLMMs fitting the skewed data with Gamma Distribution.

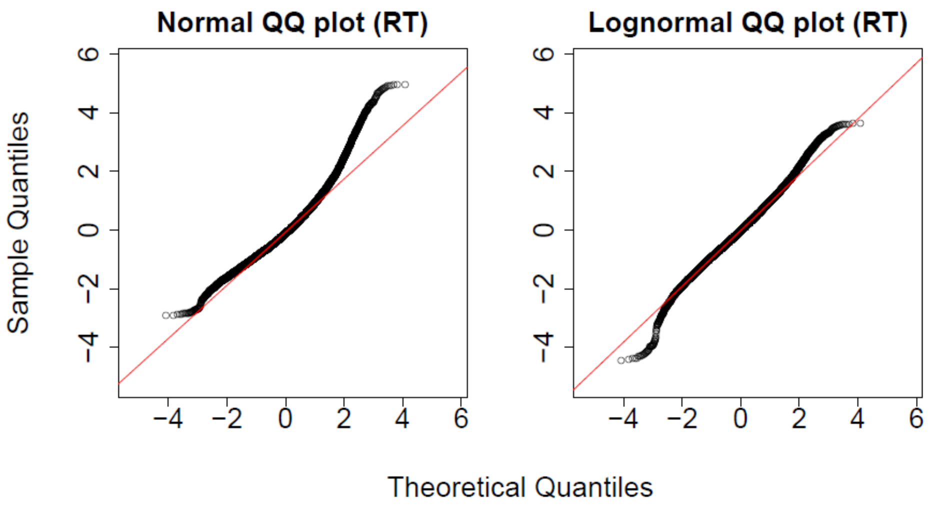
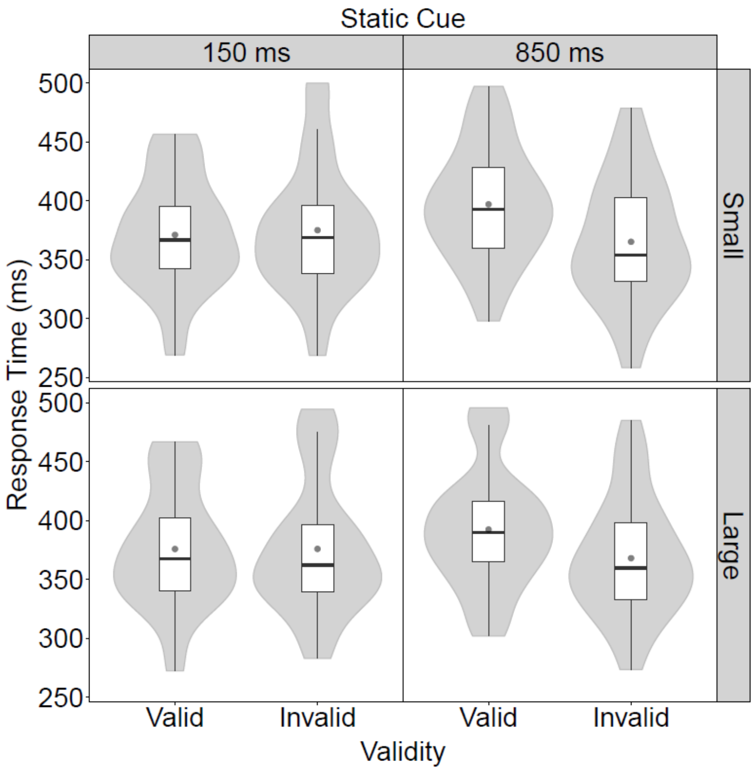


Figure 4.11. Experiment 3B. Quantile-quantile (QQ) plots. The left and right QQ-plot compares sample RT quantiles with normal and lognormal distributions, respectively.



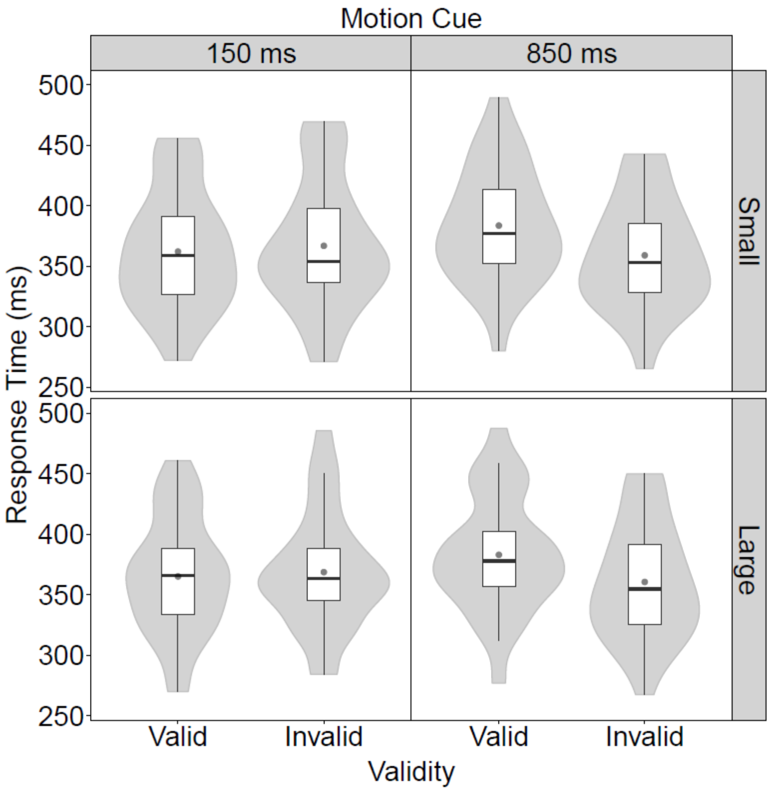


Figure 4.12. Experiment 3B. Violin plots of single-trial reaction times. The graphs on the top panel show mean values for the condition of static cues and the graphs on the bottom panel show mean values for the condition of motion cues. In each panel, the graphs from left to right show mean values for the conditions with SOA of 150 and 850 ms. The graphs from top to bottom present mean values for the conditions with small and large cues. Mean RTs (ms) are presented as boxplots. The lower and upper hinges correspond to the 25th and 75th percentiles. The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black points represent means. The violin plot outlines show kernel probability density.

Descriptive Statistics of Error Rates

Separate analyses were conducted on error rates for static and motion cueing. For static cueing, participants committed false alarms in 0.09% of the target-absent catch trials. In stimuli-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 0.55%, failed to respond within 750 ms (“too late”) on 0.22% of the trials and pressed key within 150 ms on 0.12%. For motion cueing, participants committed false alarms in 0.08% of the target-absent catch trials. In stimuli-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 0.52%, failed to respond within 750 ms (“too late”) on 0.18% of the trials and pressed key within 150 ms on 0.21%. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 4.13 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 4.13 will not add up to the overall error rate.

GLMM on Reaction Times

The following analysis was conducted on the RTs in each trial.

I tested various models, increasing model complexity stepwise (see Table 4.2). I always included Cue Type, Size, SOA, Validity, and their interaction as fixed effects. Subjects served as a random factor in all models. Model 1 served as the simplest model because it postulates a random intercept for each subject. The model takes into account that participants may vary in their average response times. Model 2, 3, 4, 5 and 6 have additional random slopes to model subject-specific effects of Cue Type, Size, SOA, Validity (the relative location between the cue and target), both of Cue Type and SOA, and both of Size and SOA, respectively. The inclusion of these random slopes relaxes the assumption that the fixed effect of Cue Type or/ and Size or/ and SOA or/ and Validity would be the same across participants. The results for all models are summarized in Table 4.2.

Table 4.2

Model comparison of models with increasingly complex random-effects structures (*df*: the number of parameters in the model, involving the coefficients of the fixed effects of the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood test between successive models).

Models	*df*	AIC	BIC	log-likelihood	χ^2	df_{χ^2}	*p*-value
M1: RT ~ Cue Type * Size * SOA * Validity + (1 | s)	18	245877	246021	-122920			
M2: RT ~ Cue Type * Size * SOA * Validity + (1 + Cue Type | s)	20	245818	245978	-122889	62.80	2	$\ll$0.0001
M3: RT ~ Cue Type * Size * SOA * Validity + (1 + Size | s)	20	245878	246039	-122919	0	0	1
M4: RT ~ Cue Type * Size * SOA * Validity + (1 + SOA | s)	20	245130	245290	-122545	748.77	0	$\ll$0.0001

M5: RT ~ Cue Type * Size * SOA * Validity + (1 + Validity | s)	20	245799	245959	-122879	0	0	1
M6: RT ~ Cue Type * Size * SOA * Validity + (1 + Cue Type + SOA | s)	23	245067	245251	-122510	738.45	3	$\ll$0.0001
M7: RT ~ Cue Type * Size * SOA * Validity + (1 + Size + SOA | s)	23	245134	245318	-122544	0	0	1

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between factors ($r < 0.99$). As Model 6 has the lowest BIC (Bayesian Information Criterion) and AIC (Akaike Information criterion), I selected it as the most parsimonious model among the models tested. Model 6 includes the by-subject random intercepts and by-subject random slopes for Cue Type and SOA.

Fixed Effects of RTs

A significant main effect of Cue Type was found, χ^2 (1) = 29.084, $p < .001$, for responses to trials with motion cues were 9 ms faster than with static cues. A significant main effect of Validity was found, χ^2 (1) = 270.341, $p < .001$, for responses to trials in the valid condition were 12 ms slower than the invalid condition. A statistically significant interaction between the Size and SOA was found, χ^2 (1) = 4.593, $p = .03$, and was further investigated (χ^2 Test, *p*-value adjusted after Bonferroni). The results showed that for the short SOA responses to trials with small cues were 3 ms significantly faster than trials with large cues ($p = .02$), but not significantly different for the long SOA. A statistically significant interaction between the Cue Type and Validity was found, χ^2 (1) = 8.737, $p = .003$, and was further investigated (χ^2 Test, *p*-value adjusted after Bonferroni). The results showed that for the valid condition, responses to trials with static cues were 11 ms slower than trials with motion cues ($p < .001$), and for the invalid condition, responses to trials with static cues were 7 ms slower than trials with motion cues ($p < .001$). A statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 387.786, $p < .001$. This interaction was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to trials in the valid condition with 850 ms SOA were 20 ms slower than trials in the valid condition with 150 ms SOA ($p < .001$), 17 ms slower than trials in the invalid condition with 150 ms SOA ($p < .001$), 26 ms slower than trials in the invalid condition with 850 ms SOA ($p < .001$).

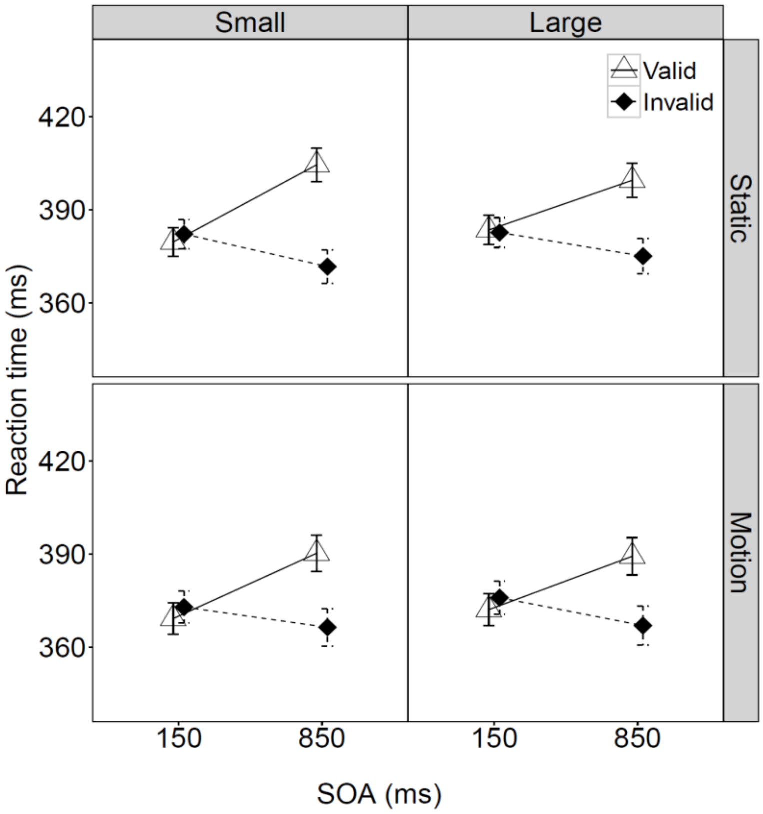
For hypothesis testing, first I examine whether response times for stimuli of the small cue are faster than the large cue, for static or motion cues. However, there were no significant main effect of Cue Size, χ^2 (1) = 2.702, $p = 0.10$ and no significant interaction effect of Cue Type by Size, , χ^2 (1) = 0.143, $p = .70$. These means that size did not have significant effect on target detection, either for static or motion cues. Therefore, no further contrasts were needed for this hypothesis.

The second hypothesis testing is for examine whether the cue size affect facilitation and IOR, and, if yes, whether the effect of size on facilitation and IOR were different between static and motion cues.

First I examined whether whether the existence of facilitation and IOR with small and large cues. The significant interaction effect of Size by SOA by Validity, χ^2 (1) = 5.174, $p = 0.02$, was further investigated (χ^2 Test, *p*-value adjusted after Bonferroni). The results showed that with 150 ms SOA, there were no significant differences between the responses to trials in valid condition and invalid condition with either small or large cues. With 850 ms SOA, responses to trials in valid condition with small cues were 28 ms slower than invalid condition with small cues ($p < .001$); responses to trials in valid condition with large cues were 23 ms slower than invalid condition with large cues ($p < .001$). These confirmed no facilitation in trials with 150 ms SOA but IOR in trials with 850 ms SOA with both small and large cues. I then tested whether there were any differences in the magnitude of IOR produced by different type of cues. The results showed that the IOR by small cues were 5 ms significant stronger than the IOR produced by small and large cues, $p= 0.03$.

Second I examined whether whether the existence of facilitation and IOR with small and large cues, in the static and motion condition. The marginally insignificant interaction effect of Cue Type by Size by SOA by Validity, χ^2 (1) = 3.284, $p = 0.07$, was further investigated (χ^2 Test, *p*-value adjusted after Bonferroni). With 150 ms SOA, the results showed that for static and motion cues, there were no significant differences between the responses to trials in valid condition and invalid condition with either small or large cues in either static and motion condition. With 850 ms SOA, for static cues, responses to trials in valid condition with small cues were 33 ms slower than invalid condition with small cues ($p < .001$); responses to trials in valid condition with large cues were 24 ms slower than invalid condition with large cues ($p < .001$). With 850 ms SOA, for motion cues, with 850 ms SOA, responses to trials in valid condition with small cues were 24 ms slower than invalid condition with small cues ($p < .001$); responses to trials in valid condition with large cues were 22 ms slower than invalid condition with large cues (*p* < .001). These confirmed no facilitation in trials with 150 ms SOA but IOR in trials with 850 ms SOA with both small and large cues, in both the static and motion condition.

I then tested whether there were any differences in the magnitude of IOR produced by small and large cues, in the static and motion condition, respectively. The results showed that for static cues, the magnitude of IOR produced by small cues were 9 ms significantly stronger than the IOR by large cues, echoing the result of Bayes factors mentioned earlier. For motion cues, there were no significant differences in the magnitude of IOR produced by small and large cues. As the IOR produced by small cues were significantly stronger than large cues in the static condition but not the motion condition, it indicated that cue type modulated the effect of cue size on IORs, see Figure 4.13.



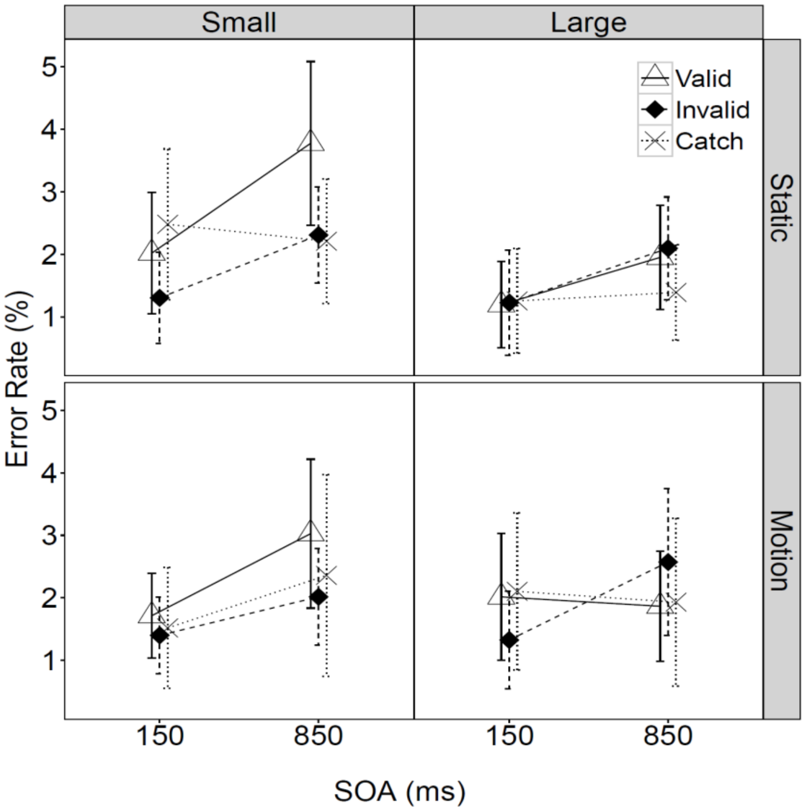


Figure 4.13. The line graph on the top panel shows the adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 6, in Experiment 3B. Error bars represent the 95% confidence intervals of the adjusted means. The line graph on the bottom panel shows the ERs (%) averaged across subjects of Experiment 3B. Error bars denote ±1.96 SEM.

Random Effects of RTs

Based on the model estimates, the individual variability of both intercept, Cue Type and SOA was computed. Figure 4.14 shows the conditional modes of the 30 participants, sorted by the values of intercept. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects.

The results suggested that individual differences were more prominent in intercepts (*SD* = 13.04) than for small stimuli (*SD* = 2.67) and 100 ms SOA (*SD* = 5.35), suggesting that the individual variability in overall response times explained more variances than the individual variability in static cues and 150 ms SOA. This is clearly shown in Figure 4.14, compared to static cues and 150 ms SOA, for the overall performances of individuals there are more participants whose confidence intervals not only do not touch the vertical line at zero (which means the grand mean and fixed effects accordingly), but also deviate from the grand mean in further extents. Specifically, except that participant 20, 14, 22 was neither significantly faster nor slower than the overall performance, as their error bars of data points tough the zero line in plot, other participants were significantly different from the overall mean RT. Participant 1 was the slowest one as its averaged RT deviated from the zero line to the rightmost edge while Participant 14 was the fastest one as its averaged RT deviated to the leftmost edge. In addition, Participant 14 and 16 has the largest deviations from the zero line to the left side, further than the other participants, indicating that they responded significantly faster than the others. Individual differences in SOA 150 ms were less prominent than the individual mean RTs as data points overall scatter near the zero line (the fixed effect for SOA 150 ms, -2.85 ms). In addition, individual differences were least pronounced in Cue Type Static as the individual data points spread tightly around the zero lines (the fixed effect for Cue Type Static, -2.85 ms). These are individual differences captured by the mixed-effect model by the implementation of random effects, which controls the built-in noise of the within-subject factor for repeated measures.

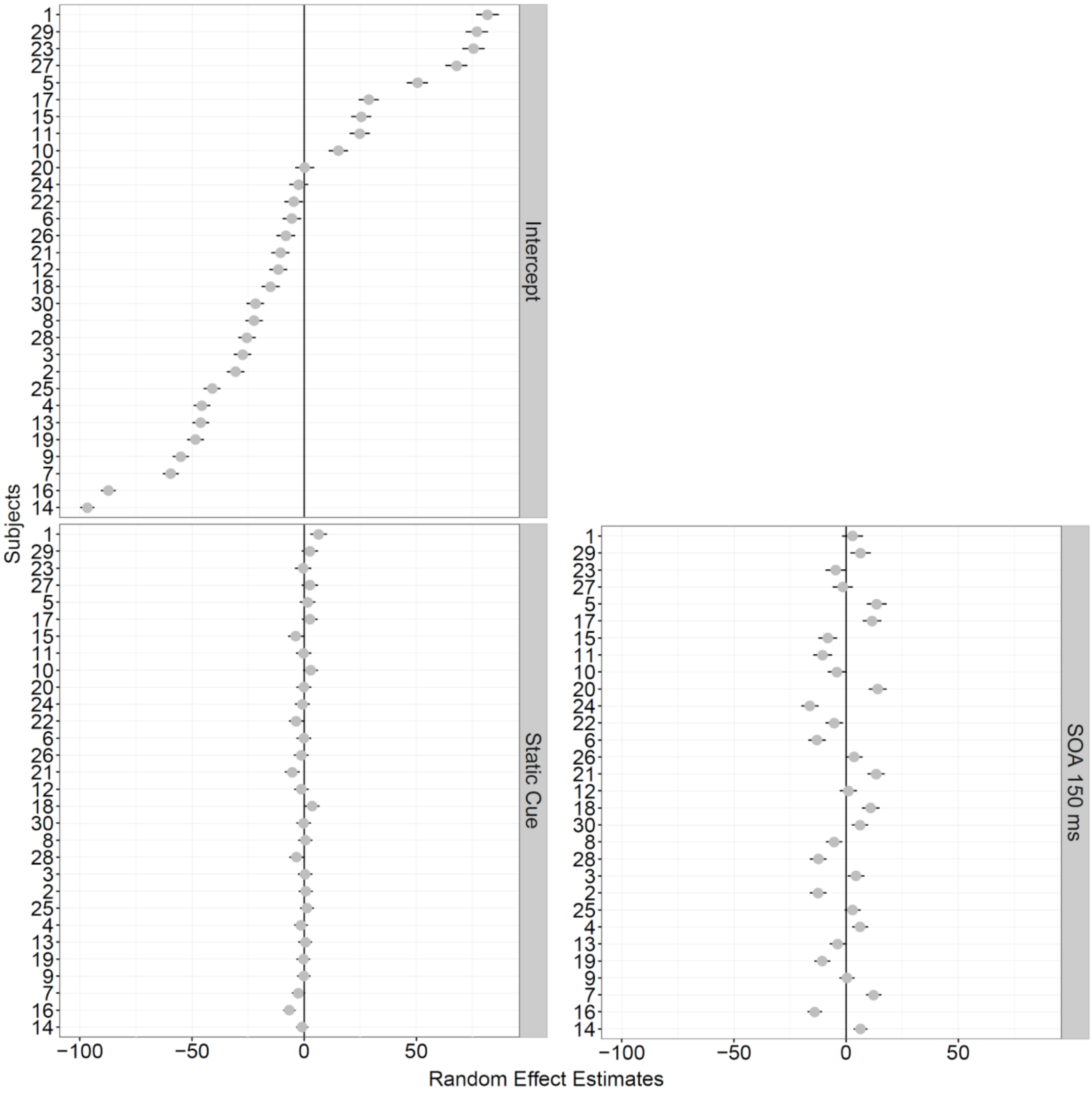


Figure 4.14. Visualization of the variance across subjects. Dotplots of random effects for each participant in Experiment 3B. The plots from top to bottom show individual estimates of random intercepts and slopes for static cue, 150 ms SOA, respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 150 ms was calculated by comparing the mean of the SOA 150 ms against the overall mean of the SOA. The vertical lines centred on 0 represent the grand mean (350.14 ms) in the first plot and corresponding fixed effect estimates in the other two plots, 4.68 ms for Static cues and -2.85 ms for SOA 150 ms. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. Participants are rank-ordered by the random intercepts. In short, the dotplots show that individual variability in overall response times explained more variances than the other random slopes. Therefore, the individual variability in overall response times were far more prominent than the other random slopes.

4.3.4 Discussion

Based on previous research, I hypothesised that, compared to static cues, the motion cues should be more salient and therefore work more effectively when detecting peripheral stimuli preceded by uninformative cues. Therefore, the motion cue should allow a better investigate of the effect of stimuli size on the detection of peripheral targets preceded by uninformative cues. In short, this experiment examined whether and how cue size affects facilitation and IOR using motion and static cues. I hypothesised that the size effect of cues should be stronger for motion cues compared to static cues.

Overall Performance

The motion cues elicited faster responses to target detection compared to the static cues. In addition, performance of target detection was better in the valid condition than in the invalid condition for motion cues. Unlike the results of Experiment 3A, size did not affect the general performances across all trials for either static or motion cues. However, for short but not the long SOA, target detection was significantly faster for small cues than for large cues, although the difference was only 3 ms. The random effects of GLMM revealed that the individual variability in overall response times were far more prominent than the other random slopes, as shown by the dotplots. The random effect of GLMM explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals.

Facilitation and IOR

As in Experiment 3A, no facilitation was observed for static and dynamic cues and for short SOA. However, IOR was again present for the long SOA in all conditions. The IOR generated by the small cues was stronger than the IOR produced by the large cues. The difference between the IOR generated by small and large cues was only 5 ms. In short, the IOR for small cues was only slightly stronger than the IOR for large cues.

Separate comparisons between the IORs for cue size in the static and the motion conditions showed that cue size affected IOR for static but not dynamic cues. The IOR for small cues was similar to the IOR for large cues in the motion condition. However, in the static condition, the IOR was stronger for small cues than for large cues. The IOR generated by small cues was stronger than the IOR generated by large cues. In short, as the cue sizes affected IOR for static cues but not for motion cues, the effect of cue sizes is stronger for static cues compared to motion cues. In addition, the random effect of mixed model explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals and present individual differences of target detection.

4.4 General Discussion

The zoom-lens model of attention (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) suggests that the attentional region can vary in size. A smaller attentional window concentrates the limited processing resources, resulting in processing stimuli with higher efficiency. The size of the attentional region can be manipulated by varying the size of the cue (e.g., Burnett, d'Avossa, & Sapir, 2013) and a positive relationship has found between cue size and reaction times for target detection (e.g., Benso, Turatto, Mascetti, & Umiltà, 1998; Turatto, et al., 2000); that is, the smaller the cue size, the smaller the attentional window, resulting in faster reaction times when detecting targets. Previous studies investigating the effect of cue size on exogenous attention showed that responses to peripheral targets preceded by peripheral cues of smaller size were facilitated compared to cues of larger size (e.g., Jiang et al., 2016; Turatto, et al., 2000). Furthermore, cue size affected the performance of target detection when targets were preceded and not preceded by cues (e.g., Burnett, d'Avossa, and Sapir, 2013). In their study, Castiello and Umiltà (1990) used a simple detection task with informative peripheral cues. The results showed that the benefits of informative cues on target detection were affected by cue size depending on SOAs. An interesting follow-up question would be whether this result is true for peripheral non-informative cues. Non-informative peripheral cues can induce facilitation and IOR, which can be considered to be benefits and costs induced by the cue, respectively, depending on SOAs. Therefore, the question of interested is whether stimulus size modulates facilitation and IOR for non-informative cues in the periphery.

4.4.1 Size

Experiment 3A used only static cues. The performance of target detection for small stimuli was worse than the performance for large stimuli, in terms of both response times and error rates. The worse overall performance for small stimuli indicates that the task for small stimuli was more difficult to perform, and this was indeed reported by participants. To solve this problem, Experiment 3B used only the large stimuli from Experiment 3A. The small cue in Experiment 3B was the same size as the large cue in Experiment 3A, whereas the large cue in Experiment 3B was twice as large as the large cue in Experiment 3A. Unlike in Experiment 3A, in Experiment 3B the overall response times in the small condition were similar to the large condition. This result is consistent with the results of previous studies that used a similar task in which targets were preceded by or not preceded by cues (e.g., Burnett, d'Avossa, & Sapir, 2013; Castiello & Umiltà, 1990). Nevertheless, in Experiment 3B, for the short SOA, target detection performance was still slightly faster for small cues than for large cues. This might indicate that the size effect generated by non-informative peripheral cues is rather weak and short-lived. The interaction between cue size and SOA was consistent with the results of previous research (Panagopoulos, von Grünau, Galera, Ivan, & Cavallet, 2006).

4.4.2 Static and Motion Cues

The zoom-lens attentional model indicates the flexibility of the size of the attention field. Indeed, a second cue could change the size of the attentional window (Turatto et al., 2000). The motion cues in Experiment 3B were five objects with increasing sizes presented successively. The motion cue either contracted or expanded, in an analogy of the dynamic process of changing the attentional "zoom lens". In this experiment, the type of animation did not influence the effect of size on target detection, as the speed of target detection was similar for the small and the large condition with motion cues. However, motion cues triggered a better overall performance in target detection compared to static cues, indicating that motion cues were more effective in alerting participants to detect peripheral targets even when the cue was uninformative and peripheral. This result is consistent with the findings of previous researches which suggested that moving stimuli effectively capture attention even when the motion is uninformative to the task (e.g., Abrams & Christ, 2003; 2005; von Mühlenen & Lleras, 2007; Shi, Weng, He, & Jiang, 2010). Furthermore, the effect of motion cues was stronger when the cue appeared at the same location as the target, compared to when the cue appeared at different locations as the target.

4.4.3 Facilitation and IOR

For Experiments 3A and 3B, there was no facilitation for the short SOA, which was a finding consistent with previous studies using non-predictive peripheral cues (e.g., Prime et al., 2006; Riggio, Bello, & Umiltà, 1998).

The cues in Experiment 3A did not facilitate target detection at the cue locations, but delayed target detection for the short SOA. The delay in target detection was unlikely to have been caused by forward masking produced by the cues. In our experiment, the shape of the cues closely matched the contour of the targets, but did not overlap with the targets, which describes the condition in which metacontrast masking occurs (see Enns & Lollo, 2000, for a review). However, metacontrast masking typically occurs in the form of backward masking, which is the mask appearing shortly after the target onset reduces the visibility of the target (Enns & Lollo, 2000). Therefore, the delay generated by the preceding cue for the short SOA is unlikely to be due to metacontrast masking. One possibility for the delay in target detection is that the delay in target detection was caused by task difficulty, particularly for the valid trials with small cues. Responses were slower for small stimuli compared to large stimuli, especially when targets were preceded by cues than without cues. This indicated a stronger effect of size for a valid compared to an invalid location of cues. Furthermore, this effect occurred for the short SOA, but not for the long SOA. Taken together, the delay for the short SOA was observed only with the small stimuli, but not with the large stimuli, possibly due to the stronger effect of size in the valid condition for the short SOA. The size effect in Experiment 3A was very likely due to a higher level of difficulty for trials with small stimuli than for trials with large stimuli. In this sense, it is possible that the delay for short SOA with small stimuli was mainly due to task difficulty caused by stimuli size. Alternatively, it is possible that the small stimuli triggered an earlier onset of IOR than the typical onset at about 300 ms (see Klein, 2000, for a review), which is similar to the findings of previous studies in which facilitation was absent but early IOR was found for short SOAs (e.g., Tassinari et al., 1994; 1998).

In Experiment 3A, size did not affect the IOR for the long SOA. However, in Experiment 3B, the IOR produced by small cues were slightly stronger than the IOR produced by large cues. Further analysis showed that the IORs generated by small cues were larger than the IORs generated by large cues, and this was only true for static cues, but not for motion cues. Therefore, for static cues, size affects IOR for the long SOA. However, this result was not observed in Experiment 3A. One possibility is that, due to the difference in sample sizes between these two experiments, and given that the effect of cue size on IOR was as small as 9 ms in Experiment 3B, this effect disappeared in Experiment 3A. The sample size was N = 16 in Experiment 3A but N = 30 in Experiment 3B, which is almost twice as many participants as in Experiment 3A. A larger sample size provides more statistical power, which is important for small effect sizes. Another possibility for the result that size affects IOR for the long SOA with static cues in Experiment 3B but not 3A is that this was due to the difference between the presentation times of cues in Experiments 3A and 3B. Cues were presented for 100 ms in Experiment 3A but 150 ms in Experiment 3B due to the animation of the motion cues. The presence duration for the static cue was the same for the motion cue (150 ms), since the static cue served as controls for the motion cue. It is possible that the longer exposure of cues, even though it was for a mere 50 ms, enhanced the effect of cue size on IOR. This may explain why the effect of cue size on IOR was observed for the static cue but not for the motion cue. More specifically, after the expanding or contracting cue animation, the cue remained static for 60 ms, which is similar to the cue duration in Experiment 3A. In short, the reason why the effect of stimuli size on IOR was found only with the static cue in Experiment 3B may be that a longer exposure of cues may enhance the effect of cue size on IOR. In order to test this possibility, further studies could manipulate the presentation times of the cues to see whether and how they influence the effect of stimulus size on IOR; that is, whether the presentation time of the cue will modulate the effect of stimulus size on IOR.

4.4.4 Physical Characteristics

As in Experiment 1 and 2, in Experiment 3A and 3B I manipulated the physical characteristics of the cue and/or target. Slower target detection was found for small compared to large stimuli in Experiment 3A. In addition, target detection was faster for motion cues than for static cues in Experiment 3B. Furthermore, the effects of stimuli size in Experiment 3A and cue type in Experiment 3B were stronger when targets appeared at the cue location than when targets appeared at the other location. This indicates that, when the manipulation of the physical characteristics of the cue and/or target did have effects on the performance of target detection, the effect was stronger when cue and target appeared at the same spatial location than when they appear at different locations. This suggests that the spatial relationship between cue and target plays a role in the effect of the physical characteristics of the cue and/or target.

Chapter 5 Double Cueing

5.1 Introduction

In his review Klein (2000) proposed that the IOR may operate akin to a “foraging facilitator”: locations that have not been searched will remain on a list for potential food sources whereas locations that have been searched and with nothing desirable found should be avoided. If IOR serves this purpose then IORs should be found at more than one cued location when multiple cues are presented at different locations before the target is presented. Indeed, previous studies confirmed that IOR was found at multiple locations when cues appeared at different locations simultaneously (e.g., Posner & Cohen, 1984) or successively (e.g., Pratt & Chasteen, 2007; Visser & Barnes, 2009; 2010). Posner and Cohen (1984) conducted an experiment with two cues appearing simultaneously and found significant IOR at either location that was preceded by cues. When cues appeared successively at different locations in a multiple cueing paradigm, IOR was detected at each cued location (e.g., Pratt & Chasteen, 2007; Visser & Barnes, 2009; 2010) and the magnitude of IOR varies depends on the sequence of cues. When cues appeared successively at different locations in a multiple cueing paradigm, the most recently cued location lead to a stronger IOR while earlier cued locations lead to a weaker IOR (e.g., Danziger, Kingstone, & Snyder, 1998; Pratt & Chasteen, 2007).

When multiple cues appear at the same location, the effect generated by each cue can accumulate and the overall cumulative effect changes the responsiveness to a target appearing at this location. Visser and Barnes (2009) called this phenomenon the “cumulative effect”. It is noteworthy that IOR was stronger at locations where multiple cues appeared compared to locations where fewer cues appeared (e.g., Pratt & Abrams, 1995; Dukewich & Boehnke, 2008). In addition, Visser and Barnes (2009) found that the effect could not only be additive for IORs but also that facilitation counteracted IOR. In their Experiment 3 targets were preceded by two cues.

The interval between the onset of the first cue and the second cue was always 800 ms whereas the intervals between the onset of the second cue and target (second cue-target SOA) were either 100, 400 or 800 ms. Therefore, the interval between onset of the first cue and target was 900, 1200, or 1600 ms. When cues appear at different location successively, it is able to measure the effect generates by each cues. Since the first cue-target SOAs were at least 900 ms, the first cue generates IOR despite the length of the second cue-target SOA. However, the effects produced by the second cue varied depending on the second cue-target

SOA. Specifically, for the cue-target SOA of 100, 400, and 800 ms, the second cue generates facilitation, IOR and IOR, accordingly. The SOA 800+100, 800+400, and 800+800 ms refer to ‘the first cue-target SOA + the second cue-target SOA’. When two cues appeared at the same location, for the condition of SOA 800+400 and 800+800 ms, in which the first and second cues both produced IOR, stronger IOR were found at the location preceded by cue twice than once. These results indicated that IOR produced at the same location by two cues separately accumulated at the same location. For the condition of SOA 800+100 ms, in which the first cue generated IOR but the second cue generated facilitation, no significant effect were found when both cues appeared at the same location. This result indicated that facilitation counteract IOR when two cues appeared successively at the same location.

In summary, in a multiple cueing paradigm, when the interval between each cue and the target are long enough to generate IOR, IOR is detected at multiple cue locations; the most recently cued location generated the strongest IOR; IOR accumulates for the same location. However, it is unclear whether facilitation has similar characteristics in a multiple cueing paradigm, which leads to three questions. First, when cues appear successively at different locations, whether these cues can trigger facilitation at different cue locations. If successive cues can trigger facilitation at different locations then a follow-up question would be whether the most recently cued location generates a stronger facilitation. A third question is when cues appear at the same location in short succession, whether the facilitation effects generated at the same location can accumulate (the cumulative effect). Investigating the characteristics of facilitation allows us examining the attentional account of facilitation proposed by Posner and Cohen (1984). According to the attentional account, facilitation is induced by a covert shift of attention towards the cue location, resulting in a facilitated response to the upcoming target at the cue location compared to other uncued location(s). Based on this account, attention shifts to the first cue location at the beginning and later shifts to the subsequent cue locations. In this case, it is possible that only the responses to targets appearing at the most recent cue location are facilitated but not to targets at locations that were cued earlier. Therefore the hypothesis derived from the attentional account is that for cues in short succession, facilitation should not occur at different locations and thus, the result that the most recently cued location generates a stronger facilitation as well as the cumulative effect should be observed.

In order to test these hypotheses I used the double cueing with two cues appearing successively at the same or different location(s), similar to the manipulation in Visser and Barnes (2009). Critically, I also manipulated the intervals between the onset of these two cues and the onset between the second cue and the target. The combinations of two intervals were 100+100, 100+800, and 800+100 ms, which I will refer to as SOA-D, the stimulus onset asynchrony for the double cueing. For example, SOA-D 100+800 ms means that the interval between the onset of Cue 1 and onset of Cue 2 was 100 ms and the interval between the onset of Cue 2 and the onset of the target was 800 ms. Therefore, the interval between onset of Cue 1 and the onset of target was 900 ms and the interval between the onset of Cue 2 and the onset of target was 800 ms. These intervals between the cues and the target were long enough to generate IOR (see Klein, 2000). Thus, SOA-D 100+800 ms can be used to study the characteristics of IOR, such as the cumulative effect. SOA-D 800+100 ms was used to study the relation between facilitation and IOR, that is, whether facilitation can counteract IOR at the same location. In addition, SOA-D 100+100 ms was used to study the characteristics of facilitation. It has been reported that facilitation can be observed for SOAs of 200 ms (e.g., Rafal et al., 1991; Berger et al., 1999) more than 200 ms (e.g., Berger et al., 1999).

5.2 Experiment 4A

5.2.1 Introduction

Previous research has shown that IOR was generated at different locations when preceding cues appeared at different locations simultaneously (e.g., Posner and Cohen, 1984) and successively (e.g., Pratt & Chasteen, 2007; Visser & Barnes, 2009). When multiple cues appeared at different locations successively, the more recently the location was cued, the stronger the IOR is (Danziger, Kingstone, & Snyder, 1998; Pratt & Chasteen, 2007). Besides, when multiple cues appeared successively at the same location, there was a cumulative effect on IOR. More specifically, at the same location, IORs were additive (e.g., Pratt & Abrams, 1995; Dukewich & Boehnke, 2008) and facilitation counteracted IOR (e.g., Visser & Barnes, 2009). However, it remains unclear whether facilitation also has comparable characteristics to IOR. More specifically, when cues appear in quick succession, whether these cues can trigger facilitation at different cue locations, whether the most recently cued location generates a stronger facilitation, and whether facilitation accumulates (the cumulative effect). By investigating characteristics of facilitation I can test the attentional account, according to which facilitation should have none of these characteristics. In Exp. 4A I used two successive cues in the Posner paradigm. By systematically varying SOA-D and the relative location between the cue and target I studied the characteristics of facilitation as well as IOR.

5.2.2 Method

Participants

A total of *N* = 20 neurotypical students from the University of Glasgow (mean age = 20.8 years, SD = 2.5, 9 males, 11 female) participated in the experiment. All observers had normal or correct-to-normal visual acuity and were naive to the purpose of the experiment. The experiment adhered to BPS guidelines and was approved by the College of Science and Engineering Ethics Committee, University of Glasgow. Participants gave written consent and received £4 for their participation.

Apparatus and Materials

Stimuli were displayed on a colour Dell LCD computer monitor (21 inches) at a viewing distance of 57 cm. The right button on a response box (Black Box Toolkit) connected to a Dell PC served as the input device. The experiment was run in PsyToolkit, a software for programming psychological experiments and surveys on the Linux operating system (Stoet, 2010). Participants were seated in front of the screen with their head positioned on a chin rest.

All stimuli were presented in white on a black background (see Figure 5.1). The fixation cross subtended 3.1° at the centre of the screen and was composed of a vertical and horizontal line 0.1° wide. Two empty square placeholders, horizontally offset 11° to the left and right of the fixation cross, were displayed in the periphery. The placeholders were 5.1° wide and 5.1° high and were composed of lines 0.15° in width. They indicated the possible location of the two cues and the target. A cue was superimposed on the placeholder and consisted of an empty square with a line thickness of 0.45°. The target was a filled white square measuring 0.8°. The cues and target were centred on the same positions as the placeholders to the left and right of the fixation cross.

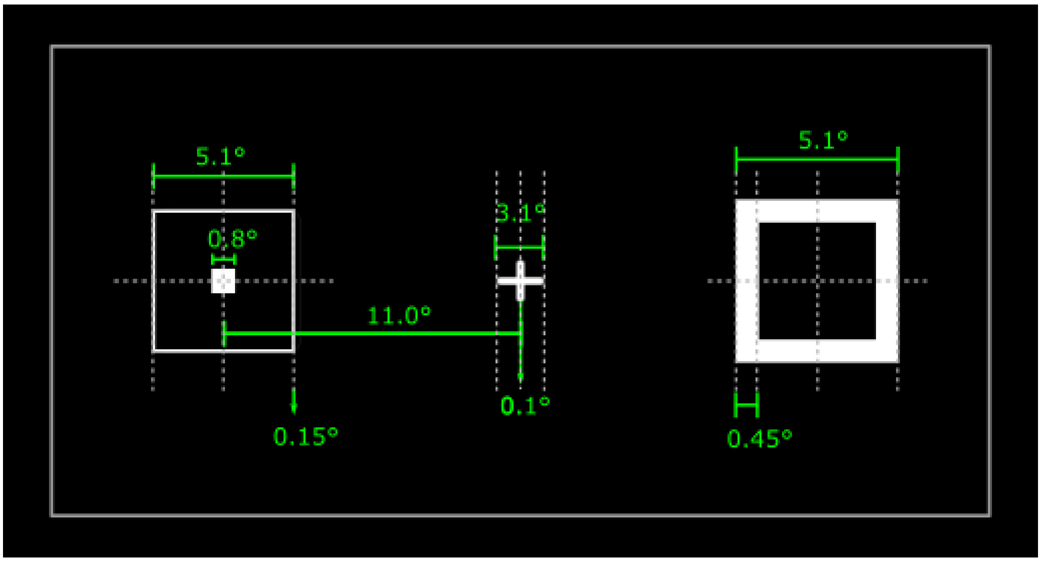


Figure 5.1. Illustration of the stimulus display. Visual angles in degrees are indicated in Green and were not shown during the stimulus display. Stimulus components from left to right are a placeholder on the left (open square) with the target inside (filled square), fixation cross at the centre and a cue (thick open square) superimposed on the second placeholder on the right.

Design

This experiment had a within-subject design including the single- and double-cue conditions. In the single-cue condition, the target was preceded by a single cue whereas in the double-cue condition, the target was preceded by two successive cues. In the single-cue condition, a standard two-factorial design was applied. The first factor was stimulus onset asynchrony (SOA) with levels 100 and 800 ms, the interval between the onset of the cue and the target. Cues always appeared for 50 ms. The second factor was Validity: in valid trials, the target appeared at the same horizontal location in the periphery as the cue whereas in invalid trials, the target appeared at the opposite horizontal location in the periphery. All trial conditions appeared with equal probability in a randomly intermixed order. In the double-cue scenario, I also employed a two-factorial design. The first factor was SOA-D (the SOA in the double-cue condition) with three levels, 100+100ms, 100+800ms and 800+100ms. The first number of each level represents the interval between the onset of Cue 1 and the onset of Cue 2. The second number represents the interval between the onset of Cue 2 and the target. In trials with SOA-D 100+800ms, for example, Cue 1 appeared for 50 ms followed an interval of 50 ms then Cue 2 appeared for 50 ms followed by an interval of 750 ms

Following Visser and Barnes (2009), the trials were grouped as follows: (1) one-back trials (invalid-valid), in which Cue 1 was invalid and Cue 2 was valid; (2) two-back trials (valid-invalid), in which Cue 1 was valid and Cue 2 was invalid; (3) double valid trials (valid-valid), in which Cue 1 and Cue 2 was valid; 4) double invalid trials (invalid-invalid), in which Cue 1 and Cue 2 were invalid. These trial conditions defined the second factor of the double-cueing condition: Validity-D. All trial conditions were presented in randomized order. In addition, catch trials (20% of the trials) were divided equally between blocks and randomly interspersed within blocks. In a catch trial, a cue appeared at either location but was not followed by a target.

Procedure

Participants received written instructions about the task before they performed in the experiment. In each trial a fixation cross was displayed at the center before two placeholder boxes located on the horizontal meridian to the left and right of the fixation cross were presented for 1100 ms. Participants were instructed to maintain fixation on the cross throughout each trial and to respond to the target as fast and accurately as possible by pressing the response button (regardless of the location of the target). In the single-cue condition, the cue appeared for 50 ms on the left or right of the screen, followed by a target at the same or opposite location after an interval of 50 ms or 750 ms (SOA 100ms and 800ms) . Participants were instructed to ignore the cues and respond to the target only. In the double-cue condition two successive cues appeared for 50 ms each. Either cue was followed by an interval of 50 or 750 ms, resulting in combinations of SOA-D 100+100ms, 100+800ms, 800+100ms. I did not include trials for 800 +800ms because the total SOA-D in this condition was considered as too excessive. After the second cue the target appeared. In both single- and double-cue trials, the target remained on the screen until a response was made or 750 ms elapsed, whichever happened first (see Figure 5.2). A correct detection response was instantly followed by a correct message (“good”) while a response in a catch trial and no or a late response after 750 ms in non-catch trials was followed by the error message “too slow”. When a response was detected at the onset of a cue and before the onset of a target the error message “too early” would appear immediately. Error messages were presented for 3080 ms and correct messages for 300 ms. The response time (RT) to press the button was measured from the onset of the target. Twenty percent of trials of each block were catch trials, randomly intermixed between trials. Each participant completed 619 trials over 6 blocks (single- and double-cue trials were randomly intermixed within each block).

The first block contained only 19 training trials. Each of the remaining blocks consisted of randomly intermixed 60 single-cue and 60 double-cue trials.

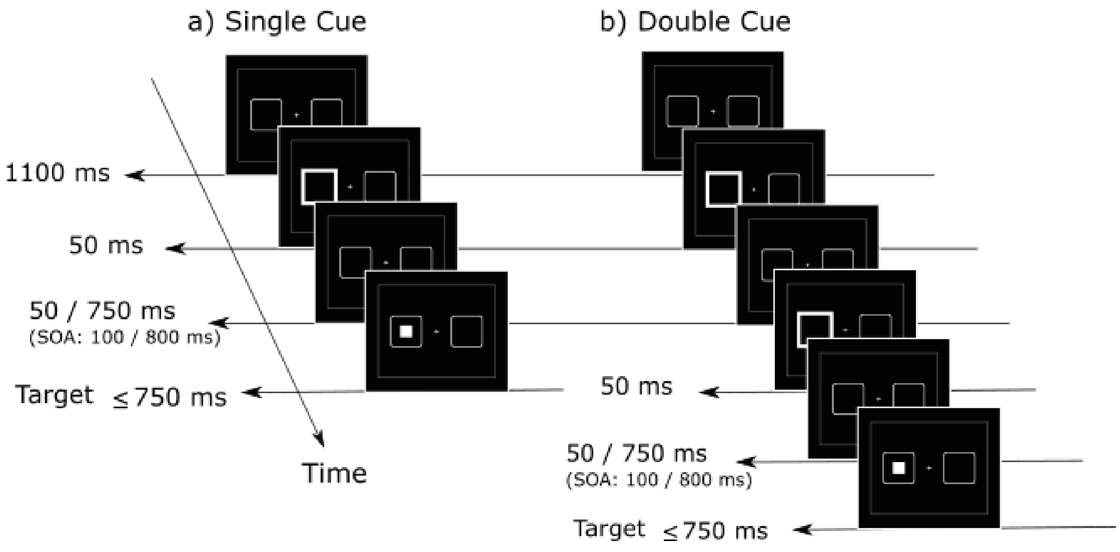


Figure 5.2. Illustration of time courses during stimulus presentation (a) the single-cue condition with invalid cue, (b) the double-cue condition with two invalid cues.

Data Analyses

The approaches used in this experiment were the same as Experiment 2. I conducted GLMMs on RTs. Error trials and catch trials were excluded from the RT analyses.

5.2.3 Results

Descriptive Statistics for Response Times

As shown in the quantile-quantile (QQ) plots of Figure 5.3 and the violin plots in Figure 5.4, the distributions of single-trial raw RTs in the current experiment were skewed, violating the assumption of normality. I employed Generalized Linear Mixed Effect Models (GLMMs, Bates et al., 2015) on single-trial RTs using the Gamma distribution as the link function.

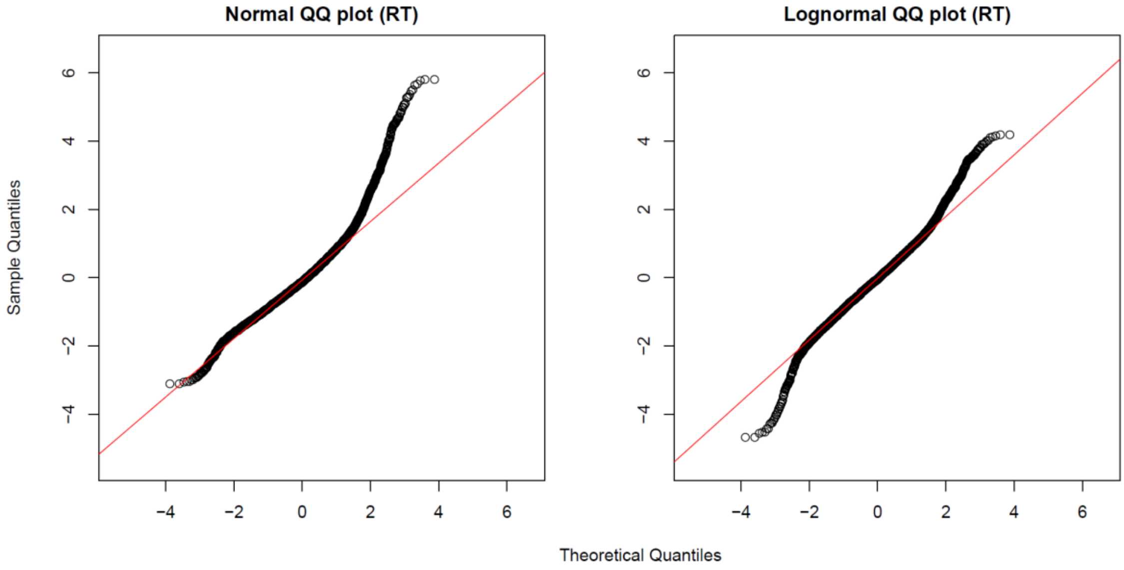
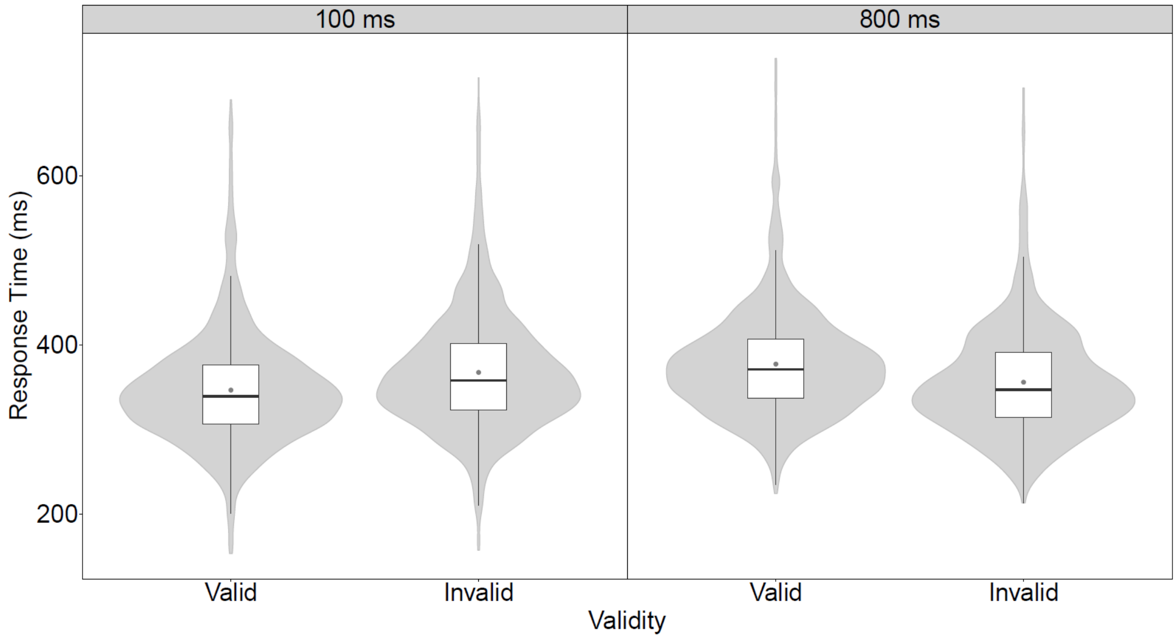
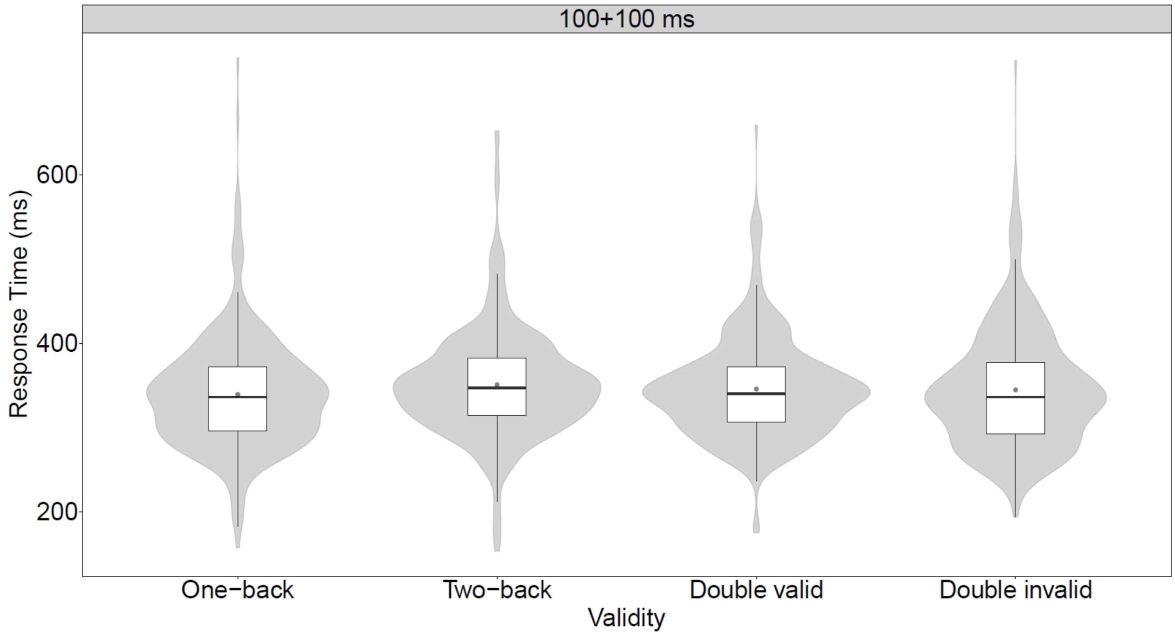


Figure 5.3. Quantile-quantile (QQ) plots for Exp. 4A. The left and right QQ-plot compare sample RT quantiles with normal and with lognormal distributions.


100 ms
800 ms
Response Time (ms)
600
400
200
Valid
Invalid
Valid
Invalid
Validity


100+100 ms
Response Time (ms)
600
400
200
One−back
Two−back
Double valid
Double invalid
Validity

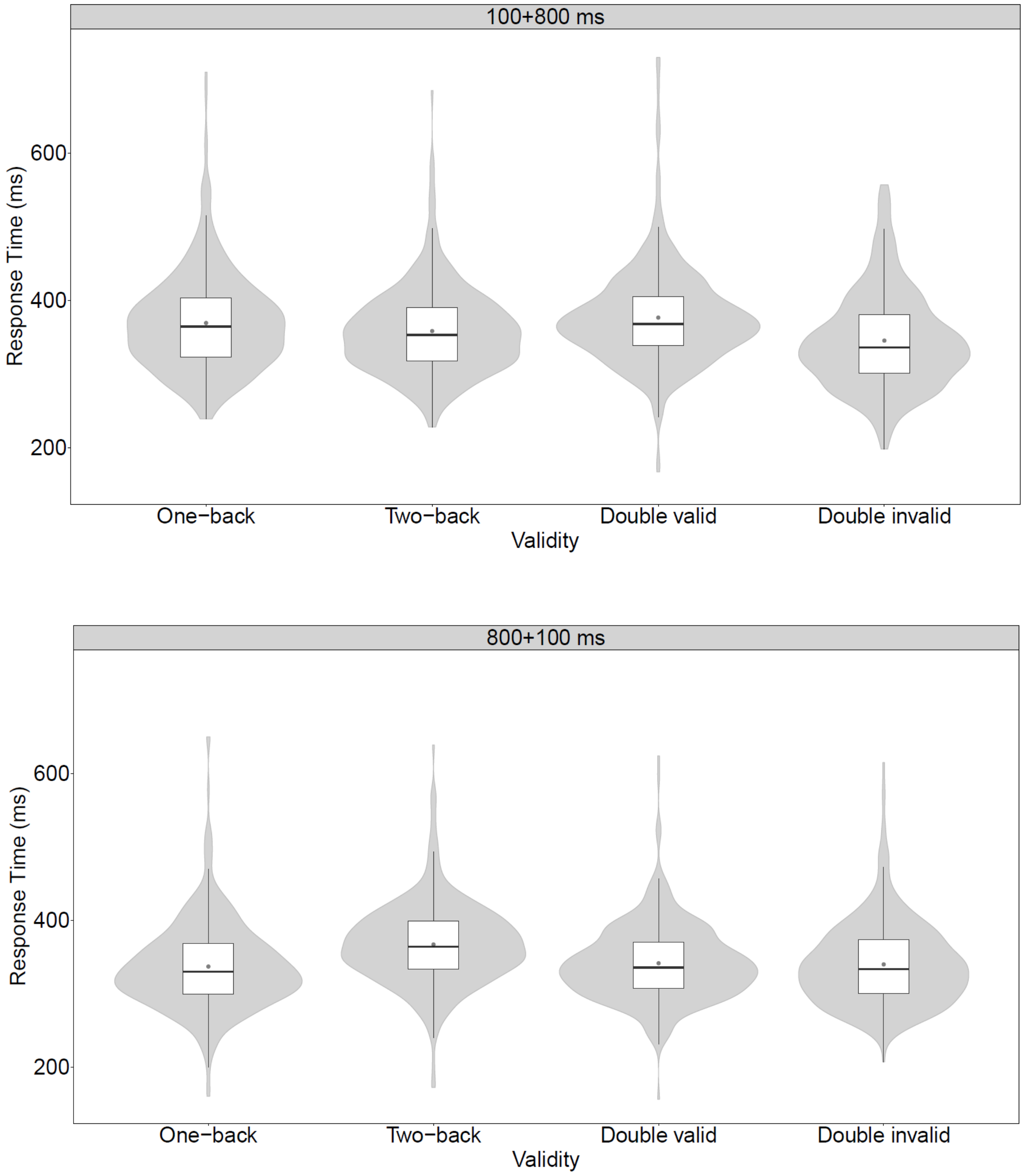


Figure 5.4. Experiment 4A. Violin plots of reaction times from single-trials. The graphs on the top row from left to right show mean values for the conditions with SOA of 100 and 800 ms in the single-cueing condition. The other three graphs from top to bottom show mean values for the conditions with SOA-D of 100+100, 100+800 and 800+100 ms in the double-cueing condition. Mean RTs (ms) of Exp. 4A are presented as boxplots. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black points represent means. The violin plot outlines show kernel probability densities.

Descriptive Statistics for Error Rates

I conducted separate analyses on the error rates for the single and double cueing.

For the single cueing, participants committed false alarms in 0.11% of the target-absent catch trials. In stimulus-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 0.53%, failed to respond within 750 ms (“too late”) on 0.15% of the trials and pressed key within 150 ms on 0.10%. For the double cueing, participants committed false alarms in 0.11% of the target-absent catch trials. In stimulus-present trials, participants committed the “too early” mistake on 1.04%, the “too late” mistake on 0.15% of the trials and pressed key within 150 ms on 0.32%. Mean RTs were computed excluding all trials where one of these four errors occurred. Noticed that the error rates were quite low (.10% - 1.04%), implying that observers neither missed nor expect many targets. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 5.5 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 5.5 will not add up to the overall error rate.

GLMM on Response Times

In order to improve the model fit and estimates, I also conducted two separate Generalized Linear Mixed Models (GLMMs, Bates et al., 2015) for the single-cue condition and the double-cue condition, respectively. The following analyses were conducted on single-trial RTs in each trial excluding error trials.

GLMM on RTs for the Single-cue Condition

I tested various random-effect models by stepwise increasing the model complexity (see Table 5.1). I always included SOA, Validity, and their interaction as fixed effects. Subjects served as the random factor in all mixed models. Model 1 is the simplest model because it only postulates a random intercept for each subject. The model takes into account that participants may vary in their average response times. Model 2, 3 and 4 have additional random slopes to model subject-specific effects of SOA, Validity (the relative location between the cue and target), and both of SOA and Validity, respectively. The inclusion of these random slopes relaxes the assumption that the fixed effect of SOA or/ and Validity would be the same across participants. The results for all models are summarized in Table 5.1.

Table 5.1

Model comparison of models with increasingly complex random-effects structures (*df*. the number of parameters in the model, involving the coefficients of the fixed effects of the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood test between successive models)

Models	*df*	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*-value
M1: RT ~ SOA * Validity + (1 | s)	6	51843	51882	-25915			
M2: RT ~ SOA * Validity + (1 + SOA | s)	8	51791	51843	-25888	55.702	2	≪0.0001
M3: RT ~ SOA * Validity + (1 + Validity | s)	8	51835	51887	-25910	0.000	0	1
M4: RT ~ SOA * Validity + (1 + SOA + Validity | s)	11	51784	51855	-25881	57.653	3	≪0.0001

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between factors (r <.99). As model fits improve with model complexity, I tried to guard against overfitting by introducing a penalty for model complexity. Therefore I employed the Akaike Information Criterion (AIC; Akaike, 1973) and Bayesian Information Criterion (BIC; Schwarz, 1978), which take into account model fit as well as model complexity in terms of degrees of freedom and number of observations. Both AIC and BIC decrease with log-likelihood goodness-of-fit (Kliegl et al., 2011). However, when the lowest AIC and BIC were attributed to different models, I did take another rule into account: compared to the AIC, the BIC uses a more conservative penalty and will thus prefer simpler models with fewer parameters, i.e., a more parsimonious model (Lewis et al., 2011). Although Model 4 has the lowest AIC, I selected Model 2, which has the lowest BIC, as the most parsimonious model among the models tested. Model 2 includes by-subject random intercepts and by-subject random slopes for SOA.

Fixed Effects of RTs in the Single-cue Condition

The main effect of SOA approached marginal significance, χ^2 (1) = 3.229, p = .07, with faster responses (-9 ms) to targets with SOA 100 ms compared to SOA 800 ms. Moreover, a statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 150.689, $p < .001$. This interaction was further investigated by contrasts (χ^2 Test, p-value adjusted after Bonferroni). The results showed faster responses (-20 ms, $p < .001$) for targets cued at the same location (valid trials) compared to targets cued at the opposite location (invalid trials) for SOA 100 ms, indicating a facilitation effect. Slower responses (+21 ms, $p < .001$) for valid trials compared to invalid trials for SOA 800 ms suggest an effect of IOR (see the left graph of Figure 5.5).

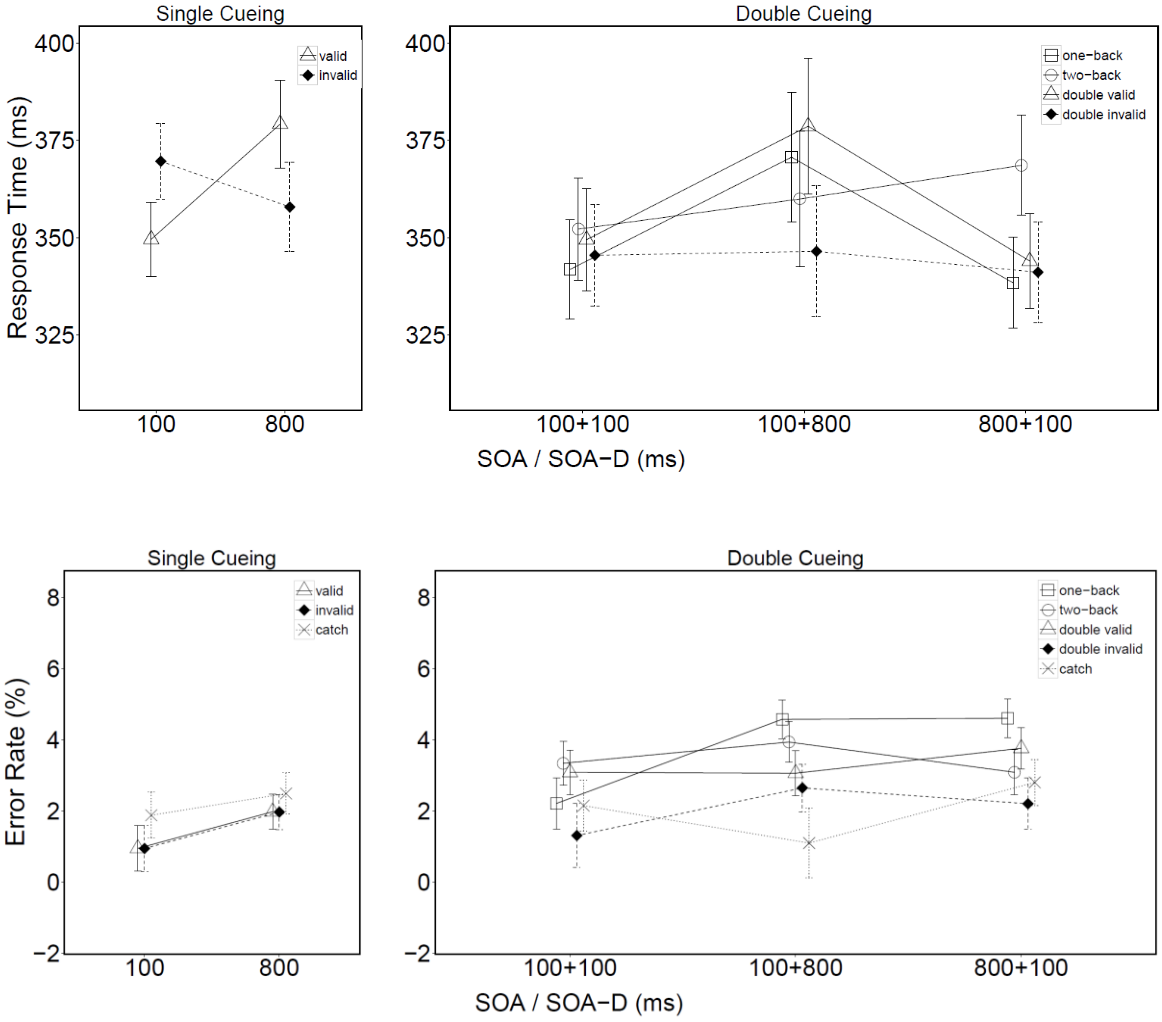


Figure 5.5. Results of Exp. 4A. The line graph on the top panel shows the adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 2 and Model 2-D, in the single and double cueing condition, respectively. Error bars represent the 95% confidence intervals of the adjusted means. The line graph on the bottom panel shows the ERs (%) averaged across subjects in the single and double cueing condition, respectively. Error bars denote ±1.96 SEM. The line graph on the left column shows mean response times and error

rates for valid and invalid cueing for SOAs of 100 and 800 ms in the single-cue condition. The line graph in the right column shows mean response times and error rates for one-back, two-back, double valid and double invalid cueing with SOA-D of 100+100, 100+800 and 800+100 ms in the double-cue condition.

GLMM on RTs for Double-cueing

I fitted various Generalized Linear Mixed Models with fixed and random effects similar to the models for single-cueing. However, I replaced SOA and Validity with SOA-D and Validity-D for double cueing. The results for double-cueing were different from single-cueing in two ways. Firstly, models that included by-subject random intercepts and random slopes for SOA-D failed to converge, that is, models with random-effects written as (1+ SOA-D | s). This was due to multicollinearity (r = 1.0) between random intercepts and random slopes for SOA-D. Therefore, I made two attempts to remove the correlation between these two random effects. In M2-D I removed the random intercept and in M3-D I replaced the random SOA-D by random Validitiy-D. In contrast to the single-cue conditions is that models with two random slopes failed to converge, i.e., models with random-effects of the form (1+ SOA-D + Validity-D | s). This may be due to the increase in model complexity as both SOA-D and Validity-D have more than two levels compared to the single-cue condition. Only models that converged were included in the model comparison (see Table 5.2). The model comparison in terms of AIC and BIC revealed that SOA-D captured more individual variability than Validity-D as a random effect. Model 2-D was the most parsimonious model tested as it had the lowest AIC and BIC. In the following we report the fixed and random effects of M2-D.

Table 5.2

Model comparison for the double-cue conditions: a model with by-Subject random intercepts only (M1-D), a model with by-Subject random slopes for SOA-D only (M2-D), a model adding random slopes for Validity-D to the intercept-only model (M3-D). (*df*: the number of parameters in the model, involving the coefficients of the fixed effects of the model)

	df	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*-value
M1-D: RT ~ SOA-D * Validity-D + (1 | s)	14	50313	50403	-25143			
M2-D: RT ~ SOA-D * Validity-D + (0 + SOA-D | s)	19	50223	50346	-25093	99.639	5	$\ll$0.0001
M3-D: RT ~ SOA-D * Validity-D + (1 + Validity-D | s)	23	50289	50437	-25121	0.000	4	1

Fixed Effects in the Double-cue Condition

A statistically significant main effect of SOA-D was found, $\chi^2(2) = 13.586$, $p = .001$, and was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to targets with SOA-D 100+800 ms were 17 ms slower than targets with SOA-D 100+100 ms, χ^2 (1) = 7.3136, $p = .02$, and 16 ms slower than targets with SOA-D 800+100 ms, χ^2 (1) = 11.7680, $p = .002$. A statistically significant main effect of Validity-D was also observed, χ^2 (3) = 58.235, $p < .001$, and was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that response times to double invalid trials were 16 ms faster than to two-back trials, χ^2 (1) = 49.6510, $p < .001$, and 13 ms faster than to double valid trials, χ^2 (1) = 33.4135, $p < .001$. In addition, compared to one-back trials, responses to two-back trials were 10 ms slower, χ^2 (1) = 19.9617, $p < .001$ and responses to double valid trials 7 ms slower, χ^2 (1) = 9.8670, $p = .01$. An interaction between SOA-D and Validity-D was also found, χ^2 (6) = 93.406, $p < .001$ and was investigated by the following contrasts.

The first series of contrasts examined the existence of facilitation and/ or IOR for different levels of SOA-D. As usual facilitation and IOR were examined by comparing response times of valid trials with invalid trials for different SOA-Ds. In the following contrasts, I compared the response times of double valid trials, one-back trials and two-back trials with double-invalid trials for different SOA-Ds. The results indicated that for SOA-D 100+100 ms, there were no significant difference between double invalid trials and double valid, one-back as well as two-back trials, confirming that no facilitation effects or IOR were present. For SOA-D 100+800 ms, responses to double invalid trials were 10 ms faster than for two-back trials, χ^2 (1) = 11.5062, p = .006, 17 ms faster than one-back trials, χ^2 (1) = 36.9978, p < .001, and 23 ms faster than double valid trials, χ^2 (1) = 66.4126, p < .001, confirming the presence of IOR effects in these three conditions. For SOA-D 800+100 ms, responses to double invalid trials were 19 ms faster than two-back trials, χ^2 (1) = 48.0086, p < .001, again suggesting an effect of IOR but no facilitation effect.

The second series of contrasts tested whether the most recent cue produced the strongest effects and whether there was a cumulative effect, i.e., whether the IORs or facilitation effects produced by successive cues at the same location in the same trial accumulated. Thereto, I first subtracted the response times of double invalid trials from the response times of double valid, one-back and two-back trials, and obtained the magnitude of IOR in double valid, one-back and two-back trials for SOA-D 100+800 and 100+800 ms. For SOA-D 800+100 ms, facilitation was expected in one-back trials and IOR in two-back trials, which were different effects. Therefore, no comparison was needed between them. In addition, if facilitation and IOR do accumulate, no significant effect should be observed in double valid trial, which has been tested in the first series of contrasts. Therefore, the second series of contrasts only conducted for SOA-D 100+800 and 100+800 ms.

To test whether the most recent cue produced the strongest facilitation or IOR, I compared the facilitation (or IOR) generated in one-back trials against two-back trials for SOA-D 100+800 and 100+800 ms. I only compared the effects that was observed in both trials for these two SOA-Ds. For SOA-D 100+800 ms the IOR generated in one-back trials was 6 ms significantly greater than the IOR generated in two-back trials, χ^2 (1) = 7.1201, p = .02. This indicates that a more recent cue produced a greater IOR effect.

To test the cumulative effect, I compared the facilitation (or IOR) generated in double valid trials against one-back trials and the facilitation (or IOR) generated in double valid trials against two-back trials. I only compared the effects that was observed in these trials for SOA-D 100+800 and 100+800 ms. For SOA-D 100+800 ms, there were no statistical differences of IORs between double valid trials and one-back trials, χ^2 (1) = 4.0090, p = .14; however, the IOR in double valid trials were 13 ms significantly greater than the IOR in two-back trials, χ^2 (1) = 21.5463, p < .0001.

Random Effects in the Single-cue Condition

Based on Model 2 random intercepts and random-effects for SOA are reported. Figure 5.6 shows the conditional modes of each of the 20 participants. The subjects are sorted by their estimated random slopes or effect for SOA 100 ms from the grand mean effect across SOAs, in order to compare their performance in single cueing with double-cueing conditions. The horizontal error bars indicate the 95% confidence interval for each estimate. The results suggest that individual variability of random intercepts (*SD* = 11.79) explained almost 5 times as much variance than the random effects of SOA (*SD* = 5.50). There are estimates of participants whose confidence intervals do not touch the vertical line at zero, which denotes the corresponding fixed effect of the intercept and slopes.

Participants varied considerably in their averaged RTs (Intercept) from the overall mean RT. 6 participants (Participant 8, 15, 12, 18, 3, 17) were not significantly faster or slower than the overall mean RT, since the 95% confidence intervals of their estimates intersect with the vertical line at zero in Fig. 5.

The other 14 participants clearly deviated from the zero line. Participant 4 responded slowest as the intercept deviated most from the zero line to the right while Participant 19 responded fastest as the intercept deviated most to the left. Individual differences in SOA 100 ms (random slopes) were not as pronounced as the individual mean RTs (random intercepts) as most of the individual estimates scatter tightly around the zero line (fixed effect for SOA 100 ms).

Random effects in the Double-cue Condition

Based on the model estimates from Model 2-D, the individual variability of SOA-D is illustrated in Figure 5.6. Figure 5.6 shows the conditional modes for the 20 participants, ranked by their estimated random slopes for SOA-D 100+100 ms. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects. Individual differences were nearly the same across all levels of SOA-D. In addition, as shown in Figure 5.6, the random effects for all SOA-Ds follow the same pattern, suggesting that similar individual effects emerged across subjects and conditions.

In general, Participant 4, who had the slowest overall responses in the single cueing condition, was significantly slower than most other participants in all SOA-D conditions, as shown in the plots on the right of Fig 5. The estimates of Participant 4 in the three plots deviate from the zero line (corresponding fixed effects for SOA-D 100+100, 100+800, and 800+100 ms) to the right. Participant 4, 11 and 13 who deviated the most from the zero line to the right in the single-cueing condition also deviated the most from the zero line to the right in all three conditions of SOA-D. Similarly, Participant 14 who deviated the second most from the zero line to the left in the single-cueing condition was the one deviated the most from the zero line to the left for SOA-D 100+100 ms and 800+100 ms and the one deviate the second most from the zero line to the left for SOA-D 100+800 ms.

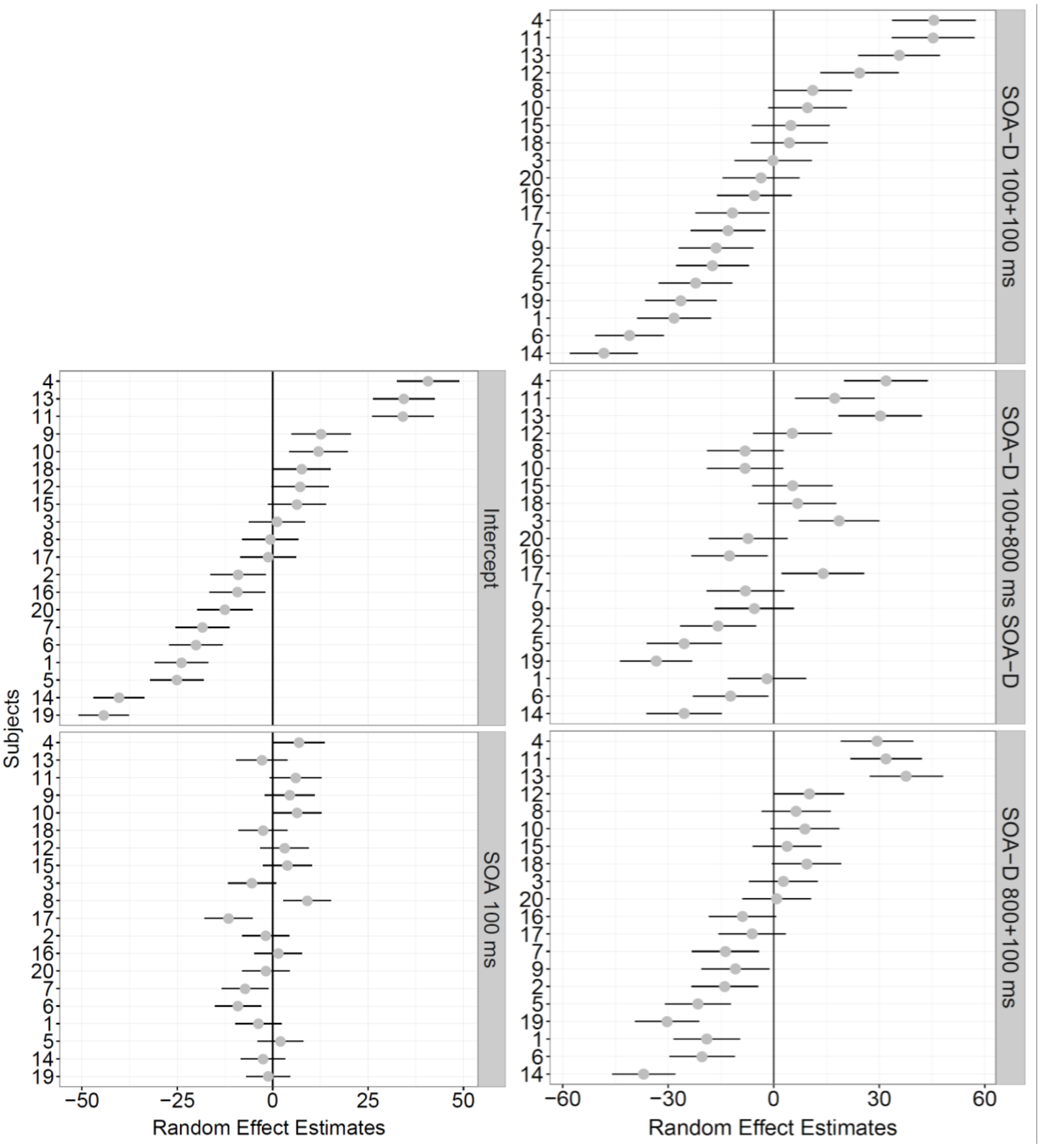


Figure 5.6. Visualization of the variance across subjects. Dotplots of random effects for each participant in Exp. 4A for the single and double cueing. The top and bottom plot on the left shows estimates of random intercepts and random slopes for SOA 100 ms, respectively. The plots in the right column from top to bottom show individual estimates of random intercepts,random slopes for SOA-D 100+100 ms, and SOA-D 100+800 ms, respectively. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. Participants are rank-ordered by the random effect of Intercept for the single cueing and by SOA-D 100+100 ms for the double cueing condition. The deviation coding scheme used here compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 100 ms was calculated by comparing the mean of the SOA 100 ms against the overall mean of the SOA. The vertical lines centered on 0 represent the grand mean and the corresponding fixed effect estimate in each plot, 364.05 ms for the grand mean and -4.47 ms for SOA 100 ms in the single-cue condition, and -5.82 ms for SOA-D 100+100 ms, 10.86 ms for SOA-D 100+800 ms, -5.04 ms for SOA-D 800+100 ms in the double-cue condition. In short, the dotplots show that individual variability in overall response times explained more variance than the other random slopes for the single-cue condition, and individual differences were nearly the same across all levels of SOA-D for the double-cue condition.

5.2.4 Discussion

The first aim of this experiment was to examine three characteristics of IOR. That is, whether IOR can appear at multiple cue locations, whether the most recently cued location generates the strongest IOR, and whether IOR generated by successive cues at the same location accumulate. The second aim was to examine whether facilitation has similar characteristics. In Exp 4A, I used two successive cues. By systematically varying SOA-D and cue location (Validity-D) I studied the characteristics of facilitation as well as IOR.

The random effects of GLMM revealed that the individual variability in overall response times were far more prominent than the other random slopes for the single-cue condition, and individual differences were nearly the same across all levels of SOA-D for the double-cue condition, as shown by the dotplots. The random effect of GLMM explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals.

In the single cueing condition, facilitation was observed for the SOA 100 ms, and IOR was detected for the SOA 800 ms, replicating earlier results in similar paradigms (e.g., Bayliss, di Pellegrino, & Tipper, 2005). For SOA-D 100+800 ms, IOR was detected in both one-back and two-back trials, which replicated the finding of previous research that IOR can appear at more than one location (Pratt & Chasteen, 2007; Visser & Barnes, 2009; 2010). In addition, IOR was increased for more recently cued locations, which is consistent with previous studies (Danziger, Kingstone, & Snyder, 1998; Pratt & Chasteen, 2007). As for the cumulative effect, although the location preceded by two cues show increased IOR than the location preceded by only one cue, it did not indicated that IOR accumulated at the same location. It is because if IOR would accumulates at the same location, IOR in double valid trials should be stronger than IOR in one-back trials. The result of Exp. 4A that no cumulative effect were found were not consistent with previous research (Pratt & Abrams, 1995; Dukewich & Boehnke, 2008). A significant cumulative effect was only found between double valid and two-back trials but not between double valid and one-back trials. For SOA-D 800+100 ms, IOR was found in two-back trials, but no facilitation or IOR was found in one-back or double valid trials. For SOA-D 100+100 ms, facilitation was not observed in two-back, one-back, or double valid trials, let alone whether the most recently cued location leads to a stronger facilitation and the cumulative effect for facilitation.

A result of interest is that facilitation was observed in the single cueing. The settings of the two critical factors, SOA and Validity, in Exp. 4A was the same as in Exp. 1 and 3A; that is, SOA included 100 and 800 ms while Validity included valid and invalid cueing. These experiments (Exp. 1, 3A, and 4A) also share similarities in other aspects of experimental conditions, such as the number of potential target locations and the shape and colour of cues and targets. However, facilitation was not found in Exp. 1, and 3A. One difference between Exp. 4A and Exp. 1 and 3A was the temporal uncertainty of the target onset. In Exp. 1 and 3A, after the presentation of the cue, there was either a target after a short or long time interval, or no target at all (catch trials). However, in Exp. 4A single-cueing conditions were intermixed with double-cueing conditions in each block. After the presentation of the first cue, there were several possible upcoming events with different timelines. For example, upcoming events after the first cue could be a second cue that appeared after two possible time intervals (100 or 800 ms), or a target, that appeared after two possible time intervals (100 or 800 ms), or no presentation at all (catch trials). In this sense, Exp. 4A generated a higher degree of temporal uncertainty for the target onset than Exp. 1 and 3A. It may be that increased temporal uncertainty raised the general alertness in participants of Exp. 4A. Thus, a higher degree of temporal uncertainty and alertness in observers might be the reason for facilitation in the single cueing. In order to investigate this possibility in Exp. 4B, I separated the single cueing and double cueing conditions into different blocks of trials. If facilitation in the single cueing conditions of Exp. 4A was due to the increased temporal uncertainty and alertness as a result of randomly intermixing the single and double cueing trials in each block, then Exp. 4B should abolish facilitation of the single cueing, similar to the results in Exp. 1 and 3A. The second aim of Exp. 4B was to examine whether separating the single and double cueing in different blocks would affect IOR in the double cueing conditions.

5.3 Experiment 4B

5.3.1 Introduction

In Exp. 4A I examined three characteristics of facilitation and IOR. That is, (1) whether IOR can appear at multiple cue locations, (2) whether the most recently cued location generates the strongest IOR, and (3) whether IOR generated by cues at the same location accumulate. In Exp. 4A I did find the first two characteristics for IOR but nothing comparable for facilitation as facilitation was not observed in the double cueing. In Exp. 4A facilitation was observed for single cueing whereas no facilitation was observed in Exp. 1 and 3A, despite these experiments and Exp 4 shared similar experimental settings. I speculated that a higher degree of temporal uncertainty for the target onset in Exp. 4A compared to Exp. 1 and 3A was responsible for the difference of results regarding facilitation between these experiments. Uncertainty and increased alertness in the observer may be due to randomly intermixing the single and double cueing conditions in the same experimental blocks of trials in Exp 4A. Therefore, the first aim of Exp. 4B was to investigate this possibility. In Exp. 4B I separated the single cueing and double cueing conditions into two blocks. If facilitation for single cueing in Exp. 4A was due to a higher level of temporal uncertainty caused by the intermixing single and double cueing in the same block, then in Exp. 4B I should no longer observe facilitation for single cueing as in Exp. 1 and 3A. The second aim of Exp. 4B was to examine whether the three IOR characteristics in double cueing observed in Exp. 4A will be affected by separating single and double cueing conditions in two blocks.

In addition, in Exp. 4B I included an SOA of 200 and 900 ms in order to make a comparison between conditions in the double cueing condition. More specifically, for the condition of SOA-D 100+100 in the double cueing, the total interval between onset of Cue 1 and target onset is 200 ms. Therefore, single cueing with an SOA of 200 ms may serve as a reference for double cueing with SOA-D 100+100 ms. Similarly, for SOA-D 800+100 and 100+800, the total interval between Cue 1 onset and target onset is 900 ms. Therefore, the single cueing with SOA 900 ms served as a reference for double cueing with SOA-D 100+800 and 800+100 ms. Except for the change in SOA, the block with SOA 200 and 900 ms was the same as the block of the single cueing with SOA 100 and 800 ms in Exp. 4A. The block with SOA 200 and 900 ms was always presented at the end of the experiment, so that the only difference between the double cueing conditions of Exp. 4A and Exp. 4B was the blocked presentations of single and double cueing conditions.

5.3.2 Method

Participants

The number of participants in the present experiment was the same as Exp. 4A, *N* = 20. All participants were neurotypical students from the University of Glasgow (mean age = 21.9 years, SD = 2.2, 4 males, 16 female). All observers had normal or correct-to-normal visual acuity and were naive to the purpose of the experiment. The experiment adhered to BPS guidelines and was approved by the College of Science and Engineering Ethics Committee, University of Glasgow. Participants gave written consent and received £6 for their participation.

Apparatus and Materials

Apparatus and materials were the same as in Exp. 4A.

Design

The factors were the same as in Exp. 4A but trials from the same condition (i.e., the single or double cueing condition) were blocked together.

Procedure

The procedure was the same as in Exp. 4A, with two exceptions. Firstly, I used a blocked design. Trials from the single cueing and trials of the double cueing condition were presented in separate blocks, rather than intermixed in the same block as in Exp. 4A. After 30 trials over 2 training blocks, participants completed 600 trials in 10 blocks, half of which contained single cueing and the other half contained double cueing in alternating sequence. Secondly, following the first 12 blocks, there were 2 additional blocks with 120 trials with SOA 200 and 900 ms. Twenty percent of trials in each block were catch trials, which were randomly intermixed in between. Each condition occurred randomly with equal probability. In total, each participant completed 750 trials in 14 blocks.

Data Analyses

The approaches used in this experiment were the same as Experiment 1. I conducted GLMMs on RTs. Error trials and catch trials were excluded from the RT analyses.

5.3.3 Results

Descriptive Statistics for Response Times

A quantile-quantile (QQ) plot (see Figure 5.7) and the violin plots (see Figure 5.8) of the response times shows that the data points in the lognormal QQ plot are closer to the main diagonal compared to the normal QQ plot, which means that the RT distributions of single-trial RTs in the current experiment were skewed, violating the assumption of normality.I employed GLMMs on single-trial RTs using the Gamma Distribution as the link function.

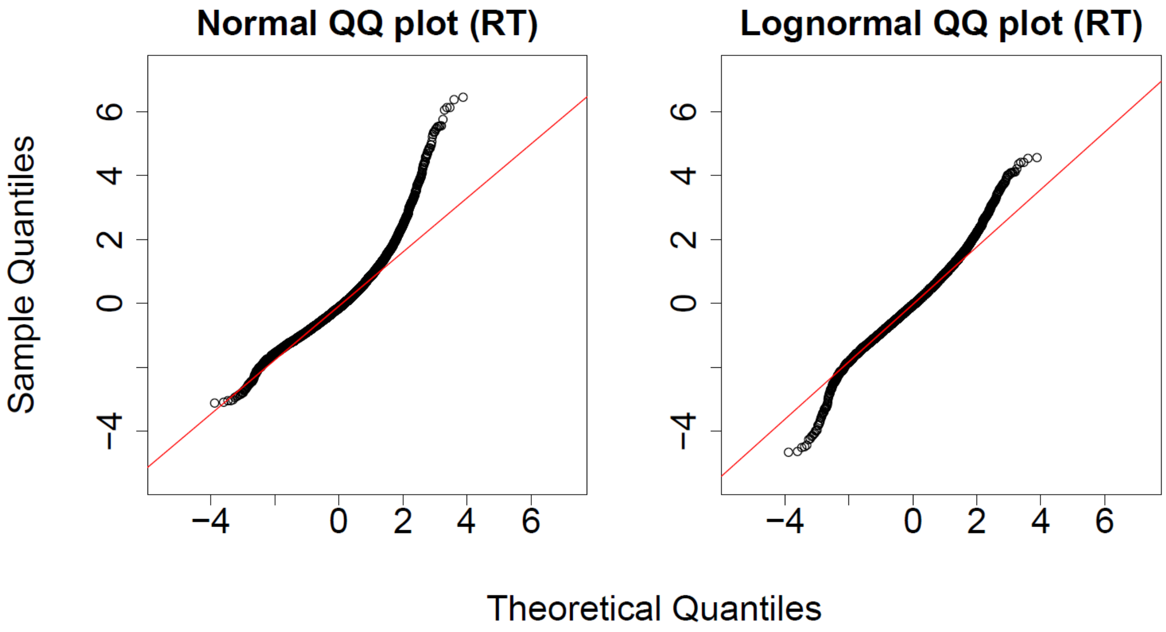
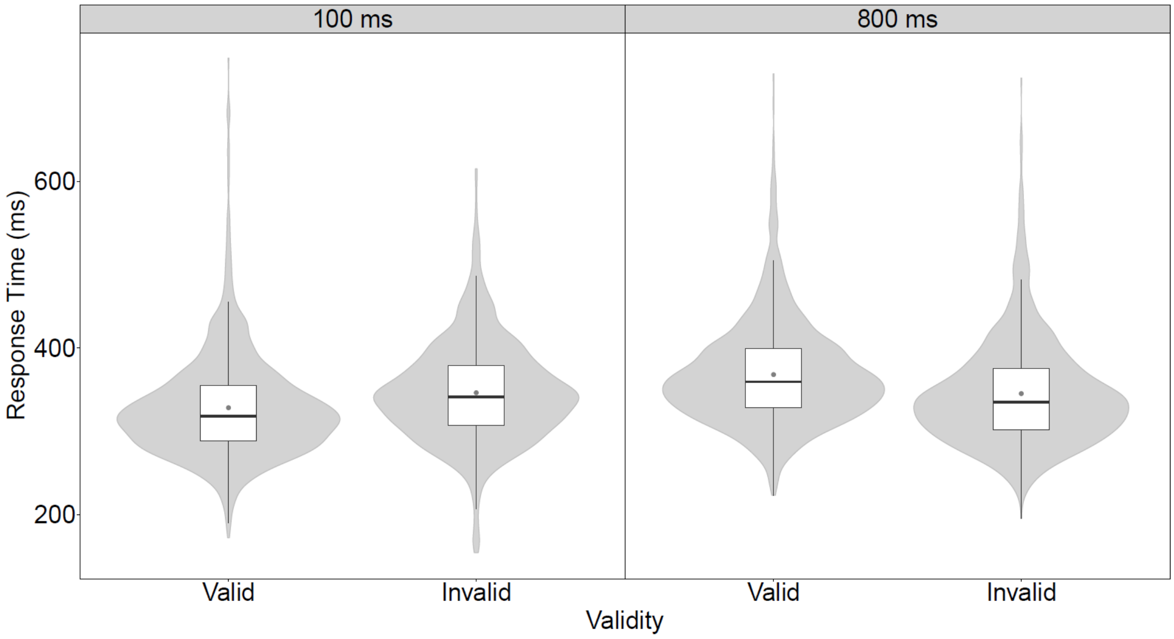


Figure 5.7. Results of Experiment 4B. Quantile-quantile (QQ) plots for RTs. The left and right QQ-plot compare sample RTs quantiles with normal and lognormal distributions.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800 ms
Response Time (ms)
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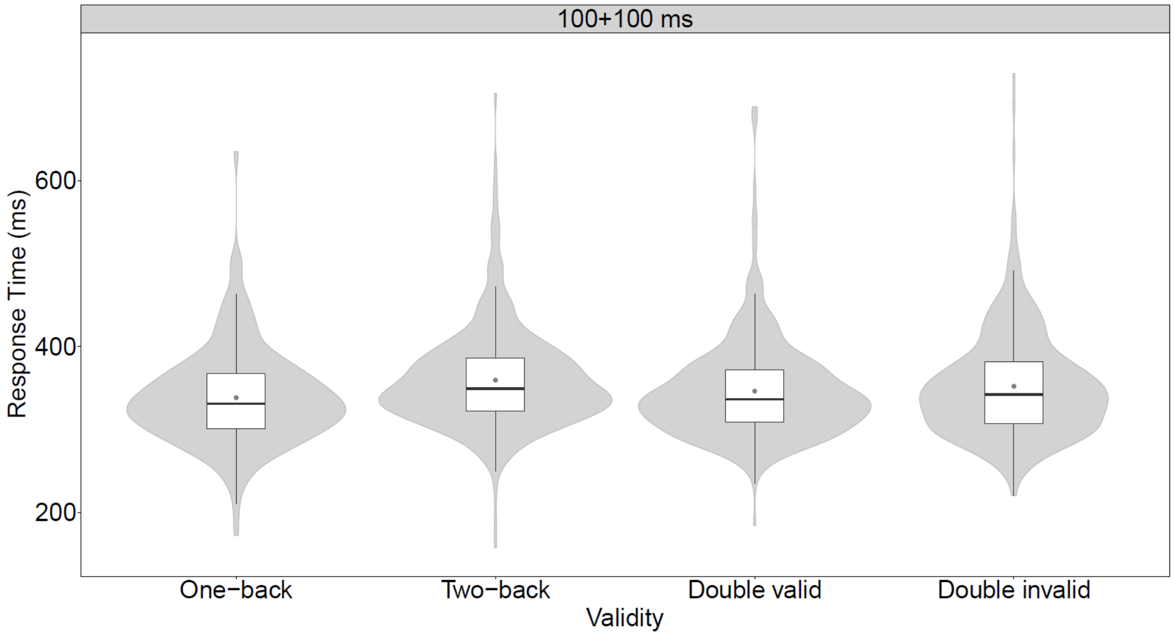
100+100 ms
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Double valid
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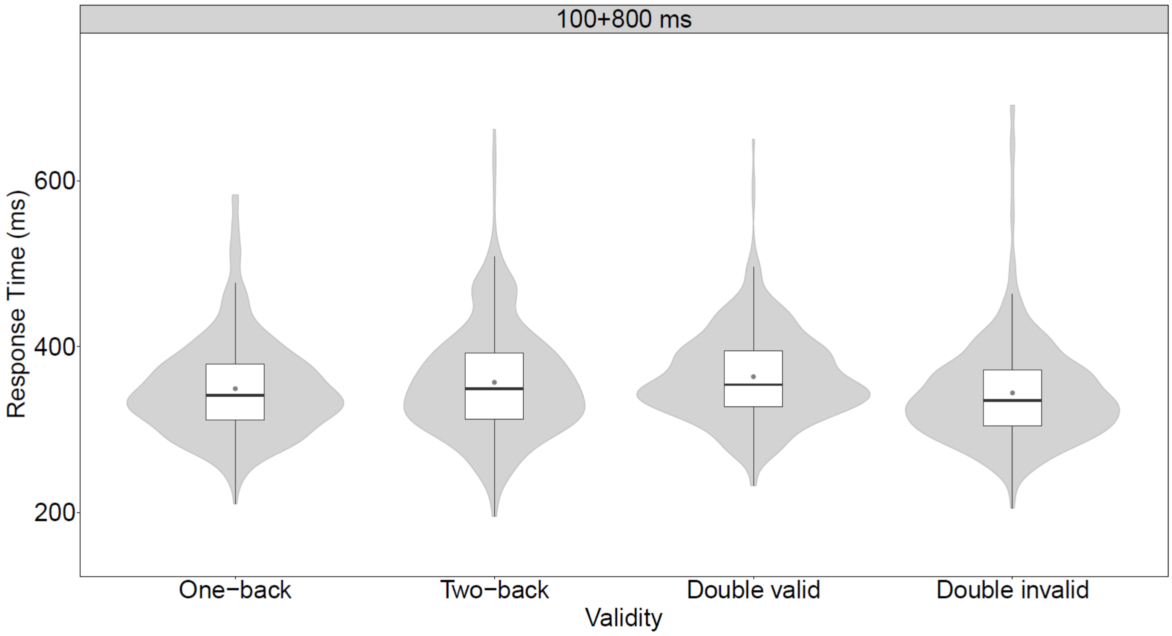


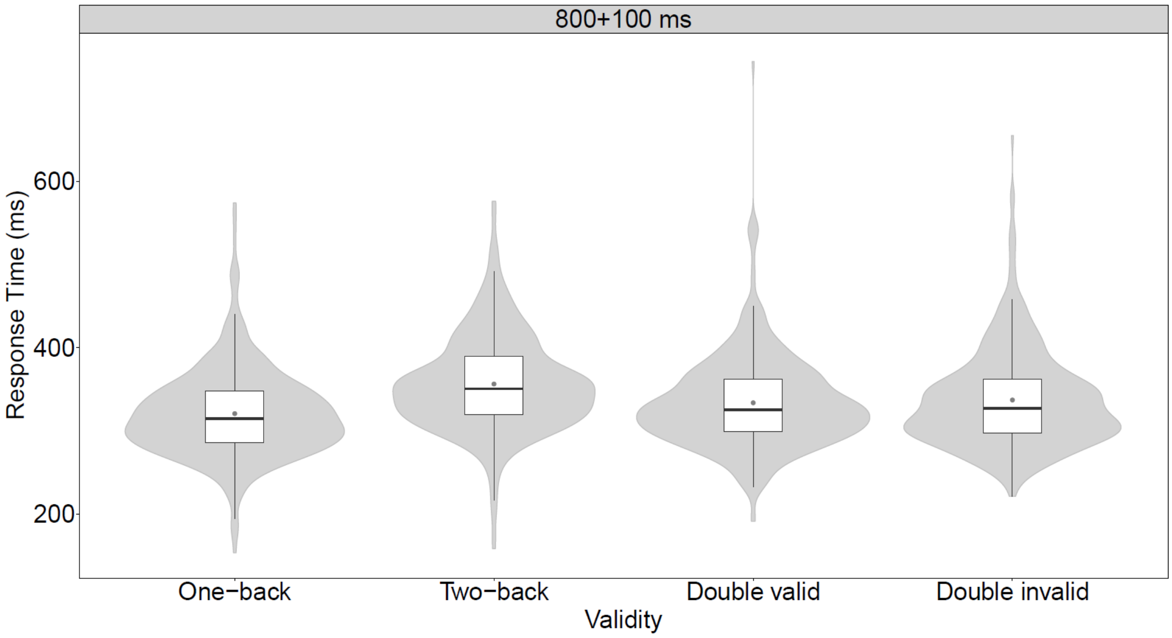


Figure 5.8. Results of Experiment 4B. Violin plots of reaction times from single-trials. The graphs on the top row from left to right show mean values for the conditions with SOA of 100 and 800 ms in the single-cueing condition. The three graphs in the second to fourth row show mean RT values for three double cueing conditions with SOA-D of 100+100, 100+800 and 800+100 ms. Each graph contains four violin plots describing RTs in one-back, two-back, double-valid and double-invalid trials. Mean RTs (ms) of Experiment 4B are presented as boxplots. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the median while the black points represent means. The violin plot outlines show kernel probability densities.

Descriptive Statistics for Error Rates

As in Exp. 4A, I conducted separate analyses on the error rates for single and double cueing. Firstly, for single cueing, participants committed false alarms in 0.07% of the target-absent catch trials. In stimulus-present trials, participants responded during the onset of cues and the onset of targets ("too early") on 0.31%, failed to respond within 750 ms ("too late") on 0.14% of the trials, and pressed the response button faster than 150 ms on 0.05%. For double cueing, participants committed false alarms in 0.07% of the catch trials with target absent. In trials with the stimulus present, participants committed to a response "too early" on 0.24%, "too late" on 0.14% of the trials and pressed the response button faster than 150 ms on 0.10%. Mean RTs were computed excluding all trials where one of these four errors occurred. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 5.9 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 5.9 will not add up to the overall error rate.

GLMM on Response Times

In order to improve the model fit and estimates of the ANOVAs, I conducted two separate GLMMs for the single-cue condition and the double-cue condition, respectively. The following analyses were conducted on single-trial RTs and errors.

GLMM on RTs for the Single-cue Condition

The random-effect models tested with increasing model complexity are shown in Table 5.3. The fixed effects and random factors were the same as Exp. 4A. Among the models tested here, Model 2 was the most parsimonious model. As mentioned before, the BIC uses a more conservative penalty and will thus prefer a more parsimonious model (Lewis et al., 2011). Therefore, albeit Model 4 has the lowest AIC, I selected Model 2, which has the lowest BIC, as the most parsimonious model among the models tested. As the mixed model in Exp. 4A, Model 2 contains by-subject random intercepts and by-subject random slopes for SOA.

Table 5.3

Model comparison of mixed models with increasingly complex random-effects structures (*df.* degrees of freedom in the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood test between successive models).

Models	*df*	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	p
M1: RT ~ SOA * Validity + (1 | s)	6	51460	51499	-25724			
M2: RT ~ SOA * Validity + (1 + SOA | s)	8	51422	51473	-25703	42.908	2	≪0.0001
M3: RT ~ SOA * Validity + (1 + Validity | s)	8	51446	51497	-25715	0	0	1
M4: RT ~ SOA * Validity + (1 + SOA + Validity | s)	11	51408	51479	-25693	43.817	3	≪0.0001

Fixed effects of RTs in the Single-cue Condition

A statistically significant main effect for SOA was found, χ^2 (1) = 23.1515, $p < .0001$, with faster responses (-20 ms) to targets with SOA 100ms compared to SOA 800ms. Moreover, a statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 166.7666, $p < .001$. This interaction was further investigated by contrasts. The results showed faster responses (-18 ms, $p < .001$) for targets cued at the same location (valid trials) compared to targets cued at the opposite location (invalid trials) for SOA 100 ms, indicating a facilitation effect. However, slower responses (+23 ms, $p < .001$) for valid trials compared to invalid trials for SOA 800 ms suggest IOR (see the left graph in Figure 5.9).

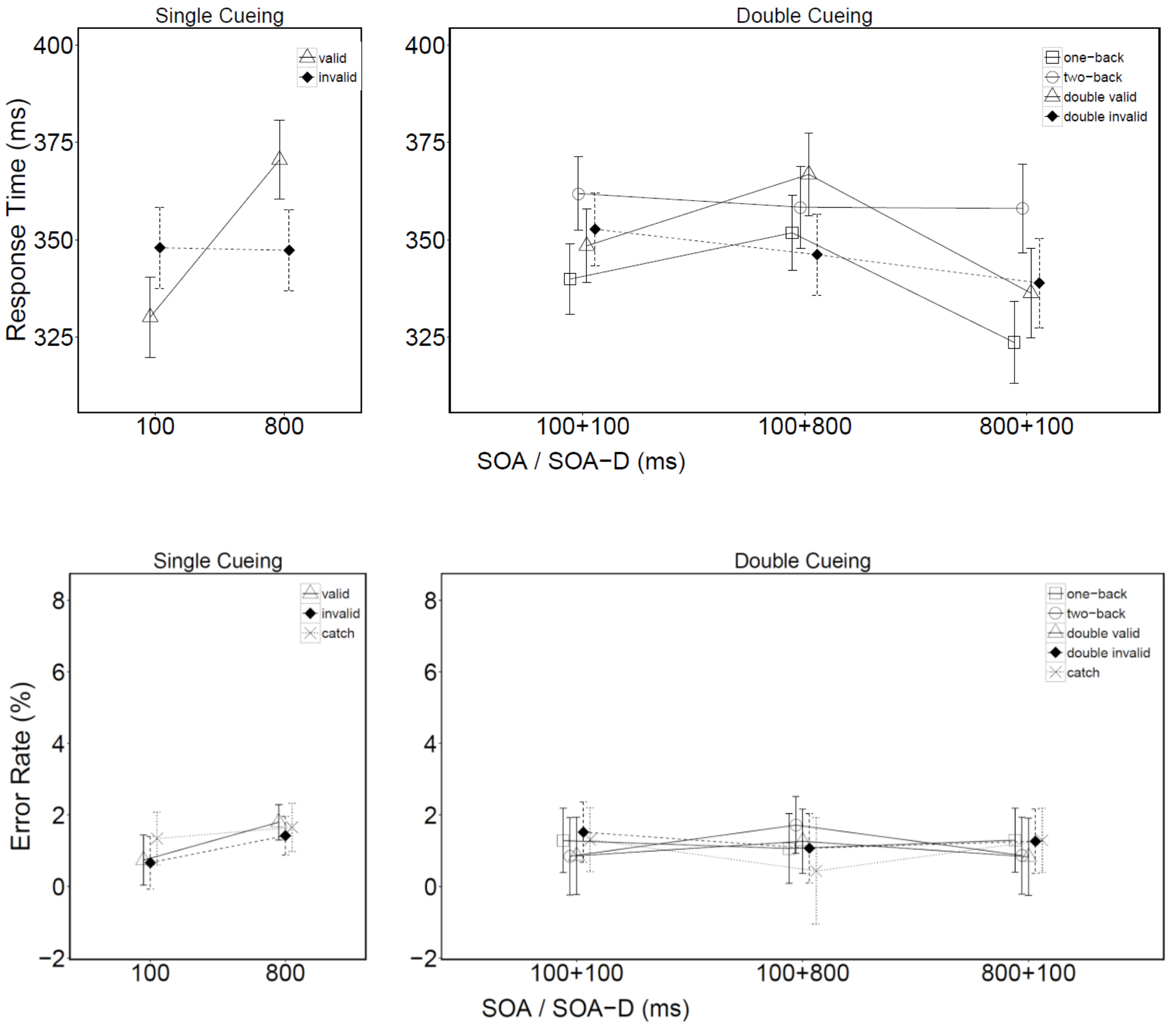


Figure 5.9. Results of Exp. 4B. The line graph on the top panel shows the graph on the top row is the adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 2 and Model 2-D, in the (blocked) single and double cueing condition, respectively. Error bars represent the 95% confidence intervals. The line graph on the bottom panel shows the ERs (%) averaged across subjects in the (blocked) single and double cueing condition, respectively. Error bars denote ±1.96 SEM. The line graph in the left column shows mean response times and error rates for valid and invalid cueing for SOAs of 100 and 800 ms in the single-cue condition. The line graph on the right column shows mean response times and error rates for one-back, two-back, double-valid and double-invalid cueing with SOA-D of 100+100, 100+800 and 800+100 ms in the double-cue condition.

GLMM on RTs for the Double-cue Condition

I tested mixed models with full factorial fixed effects but various random effects as in the single-cue condition, except that I replaced SOA and Validity with factor SOA-D and Validity-D. However, dissimilar to the single-cue condition, models that included the random slopes for Validity-D failed to converge, that is models with random-effects of the form (1+ Validity-D | s) or (1+ SOA-D + Validity-D | s). Only mixed models that converged were included in the model comparison (see Table 5.4). Model 2-D was the most parsimonious model as it had the lowest AIC and BIC among the models tested.

Table 5.4

Experiment 4B. Model comparison for the double-cue conditions: a mixed model with by-subject random intercepts only (M1-D), a model that adds random slopes for SOA-D to the intercept-only model (M2-D) (*df.* degree of freedoms in the model)

	df	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*
M1-D: RT ~ SOA-D * Validity-D + (1 | s)	14	51050	51141	-25511			
M2-D: RT ~ SOA-D * Validity-D + (1 + SOA-D | s)	19	51006	51129	-25484	53.909	5	≪0.00011

Fixed Effects in the Double-cue Condition

A statistically significant main effect of SOA-D was found, χ^2 (2) = 19.457, $p < .001$, and was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses to targets with SOA-D 800+100 ms were 11 ms faster than targets with SOA-D 100+100 ms, χ^2 (1) = 10.5830, $p = .003$, and 17 ms faster than targets with SOA-D 100+800 ms, χ^2 (1) = 16.7953, $p < .001$. A statistically significant main effect of Validity-D was also found, χ^2 (3) = 105.544, $p < .001$, and was further investigated by pairwise *t*-tests (*p*-value adjusted after Bonferroni). The results showed that responses in double-invalid trials were 13 ms faster than in two-back trials, χ^2 (1) = 39.6797, $p < .001$, 7 ms slower than in one-back trials, χ^2 (1) = 13.1384, $p = 0.002$. Compared to double-valid trials, response times in two-back trials were 9 ms faster, χ^2 (1) = 17.3961, $p < .001$ and responses in one-back trials were 12 ms slower, χ^2 (1) = 34.1308, $p < .01$. In addition, compared to one-back trials, responses in two-back trials were 21 ms slower, χ^2 (1) = 100.2254, $p < .001$. An interaction between SOA-D and Validity-D was found, χ^2 (6) = 62.539, $p < .001$ and was investigated by the following contrasts (both the first and second series of contrasts).

The first series of contrasts of interest examined the existence of facilitation and/ or IOR in different levels of SOA-D by comparing the response times in double valid trials, one-back trials and two-back trials against double invalid trials for different SOA-Ds. Results showed that for SOA-D 100+100 ms, responses to double invalid trials were 9 ms faster than one-back trials, χ^2 (1) = 12.4904, p = .004, confirming a facilitation effect. However, no significant differences were found between double invalid and two-back trials, nor between double invalid trials and double valid trials, which suggests that no other facilitation effects or IOR were present. With SOA-D 100+800 ms, responses in double invalid trials were 9 ms faster than in two-back trials, χ^2 (1) = 11.2058, p = .007, and 15 ms faster than in double valid trials, χ^2 (1) = 31.7698, p < .001. This confirms that IORs were generated in these two conditions. However, no significant differences were observed between double invalid and one-back trials, χ^2 (1) = 3.9712, p > .99, which suggests that no IOR were found. For SOA-D 800+100 ms, responses in double invalid trials were 14 ms faster than in two-back trials, χ^2 (1) = 27.6449, p < .001, and 11 ms slower than one-back trials, χ^2 (1) = 19.4374, p < .001, which confirmed a inhibition and facilitation in the two conditions, respectively. As predicted, no significant differences were found between double invalid and double valid trials, χ^2 (1) = 0.5558, p > .99.

The second series of contrasts were the same as in Exp. 4A. In order to test whether the most recent cue produced the strongest facilitation or IOR, I compared the facilitation (or IOR) generated in one-back trials against two-back trials for SOA-D 100+100 and 100+800 ms. I will examine whether the most recent cue produced the strongest IOR only when significant IOR was generated in both one-back and two-back trials for SOA-D 100+800 ms. Similarly, I will examine whether the most recent cue produced the strongest facilitation only when significant facilitation was generated in both one-back and two-back trials for SOA-D 100+100 ms. However, for SOA-D 100+800 ms, IOR was found only in two-back trials but not in one-back trials, while for SOA-D 100+100, facilitation was found only in one-back trials but not in two-back trials. Therefore, no further testing was necessary.

To test the cumulative effect, I compared the IOR generated in double valid trials against one-back trials and the IOR generated in double valid trials against two-back trials for SOA-D 100+800 ms. Similarly, I compared the facilitation generated in double valid trials against one-back trials and the facilitation generated in double valid trials against two-back trials for SOA-D 100+100 ms. I only comparison only when significant IOR was observed in these trials for SOA-D 100+800 ms. Similarly, I only comparison only when significant facilitation was observed in these trials for SOA-D 100+100 ms. The results showed only significant IOR in the double valid and two-back condition for SOA-D 100+800 ms. Therefore, I compared the IOR in in the double valid and two-back condition.

For SOA-D 100+800 ms, the difference between IORs in double valid trials and two-back trials only approached significance, χ^2 (1) = 5.3786, *p* = .06.

Random effects in the Single-cue Condition

Based on the mixed model estimates of Model 2, the individual variability of the intercept and SOA are displayed in Figure 5.19. Figure 5.19 shows the conditional modes of the 20 participants with 95% confidence intervals, sorted by the random intercept. Similar to Exp. 4A, the results suggest that individual variability was more prominent for the random intercepts (*SD* = 11.25) than for random slopes of SOA 100 ms (*SD* = 4.93). This indicates that the individual RTs (random intercepts) explained more variance than the random slopes of SOA 100 ms.

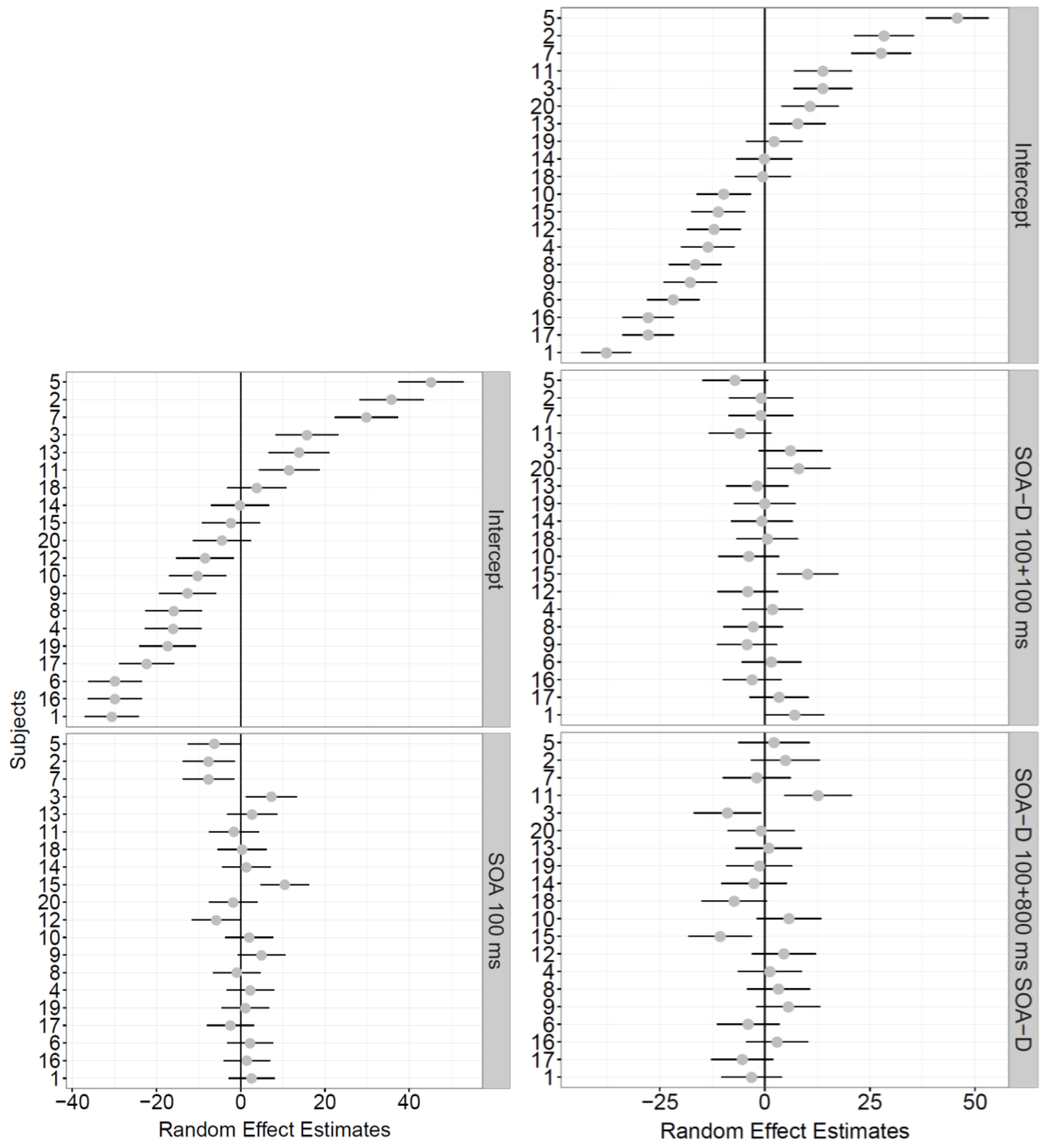


Figure 5.10. Visualization of the variance across subjects. Dotplots of random effects for each subject in Exp. 4B. The plots on the left and right show the random effects for the single and double cueing, respectively. For the left panel, the plot on the top shows estimates of individual intercepts and on the bottom individual slopes for 100 ms SOA, respectively. For the right panel, the plot on the top shows estimates of individual intercepts and the bottom two plots show slopes for SOA-D 100+100 and 100+800 ms, respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 100 ms was calculated by comparing the mean of the SOA 100 ms against the overall mean of the SOA. The vertical grey line in each plot represents the grand mean and the corresponding fixed effects estimate in each plot, 348.98 ms for the grand mean and -9.93 ms for SOA 100 ms in the single-cue condition, and 348.59 ms for the grand mean, 2.15 ms for SOA-D 100+100 ms, 7.19 ms for SOA-D 100+800 ms in the double-cue condition. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. Subjects are rank-ordered by Intercept for plots of the single cueing and double cueing. In short, the dotplots show that participants varied noticeably in their average RTs (Intercepts) from the overall mean RT than other random effects, for both single and double cueing.

Random effects in the Double-cue Condition

Based on the model estimates, the individual mean RTs and the effect of SOA-D were computed. Figure 5.10 shows the conditional modes for the 20 participants, sorted by the value of SOA-D 100+100 ms, in order to compare with the fitted model of the double-cue condition in Exp. 4A. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects. Again, individual differences were more salient for in intercepts (*SD* = 10.76) than for SOA-D 100+100 and 100+800 ms (*SD* = 5.70; 6.40).

For both single and double cueing, participants varied noticeably in their average RTs (Intercepts) from the overall mean RT, represented by the vertical line at zero in each plot for Intercept. Participant 2, 5 and 7 were the fastest three participants in terms of averaged RTs in the single cueing and remained at the top three in terms of overall RTs in the double cueing conditions. Similarly, Participant 1, 6,16 and 17 who had the slowest averaged overall RTs in the single cueing was also the slowest in the double cueing. Individual differences in SOA 100 ms, SOA-D 100+100 and 100+800 ms were less prominent as the individual data points spread closely around the zero lines (the fixed effect for SOA 100 ms, SOA-D 100+100 and 100+800 ms).

Single cueing with SOA 200 and SOA 900 ms

The result of analysis presented below is for the single cueing with SOA 200 and 900 ms.

Descriptive Statistics for Reaction Times for SOA 200 and 900 ms

As shown by the QQ plots (Figure 5.11) and violin plots (Figure 5.12), the distributions of raw RTs in the current experiment were skewed, violating the assumption of normality. I employed GLMMs that fit the single-trial RT data with Gamma Distribution.

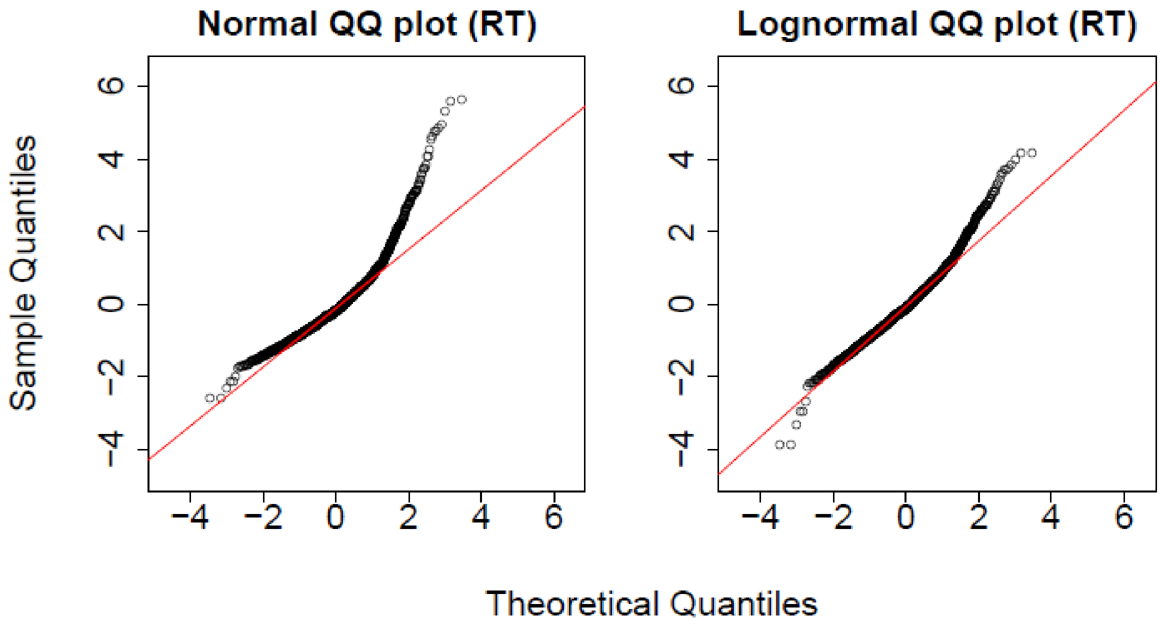


Figure 5.11. Experiment 4B. Quantile-quantile (QQ) plots for the single cueing with 200 and 900 ms. The left and right QQ-plot compare sample RT quantiles with normal and lognormal distributions.

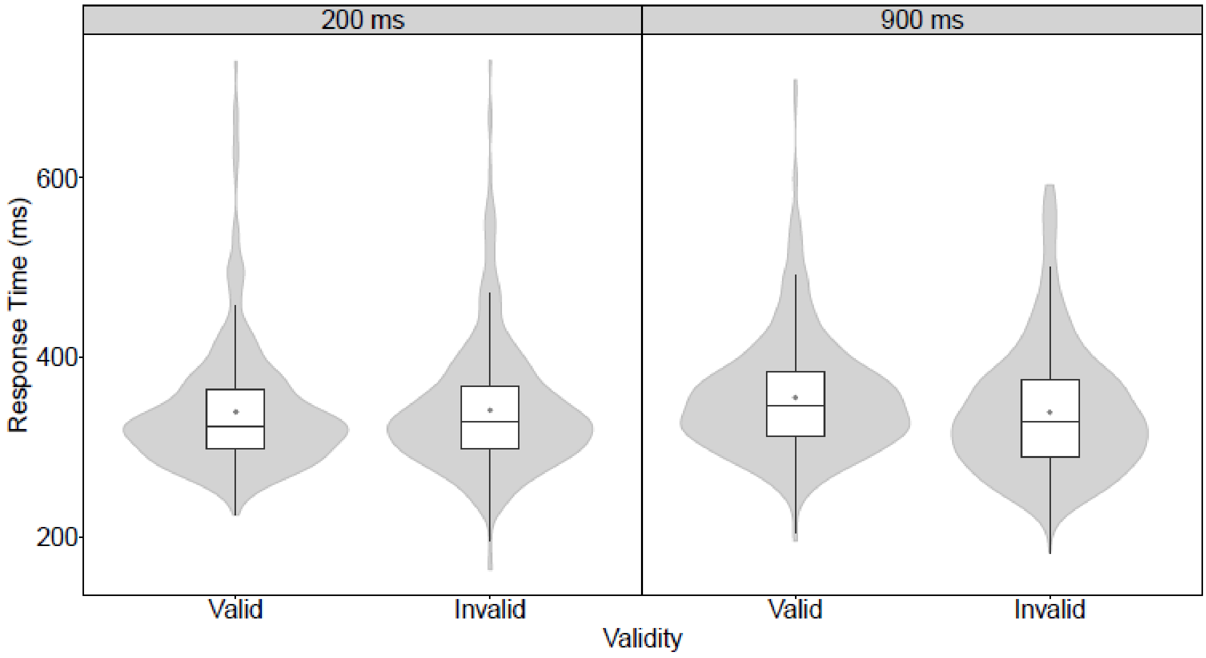


Figure 5.12. Experiment 4B. Violin plots of reaction times from single-trials for the single cueing with 200 and 900 ms. The graphs from left to right show mean values for the conditions with SOA of 200 and 900 ms. Mean RTs (ms) of Exp. 4B are presented as boxplots. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper and lower whisker extends from the hinge to the largest and lowest value within a 1.5 * inter-quartile range. Inside hinges, horizontal lines indicate the

median while the black points represent means. The violin plot outlines show kernel probability densities.

Descriptive Statistics for Error Rates for SOA 200 and 900 ms

For the single cueing, participants committed false alarms in 0.06% of the target-absent catch trials. In stimulus-present trials, participants responded during the onset of cues and the onset of targets (“too early”) on 0.16%, failed to respond within 750 ms (“too late”) on 0.07% of the trials and pressed key within 150 ms on 0.03%. Notice that these values of error rate are the mean of the overall error rate of each subject (i.e., dividing error trials by all trials). However, the error rates shown in Figure 5.13 are the mean error rates of each subject in each condition (i.e., dividing the number of error trials in a condition by the trial number in this condition). Therefore, the error rates in Figure 5.13 will not add up to the overall error rate.

GLMM on Reaction Times for SOA 200 and 900 ms

The following analysis was conducted on the RTs of each trial.

I tested various models, increasing model complexity stepwise (see Table 5.5). I always included SOA, Validity, and their interaction as fixed effects. Subjects served as a random factor in all models. Model 1 served as the simplest model because it postulates a random intercept for each subject. The model takes into account that participants may vary in their average response times. Model 2, 3 and 4 have additional random slopes to model subject-specific effects of SOA, Validity (the relative location between the cue and target), and both of SOA and Validity, respectively. The inclusion of these random slopes relaxes the assumption that the fixed effect of SOA or/ and Validity would be the same across participants. The results for all models are summarized in Table 5.5.

Table 5.5

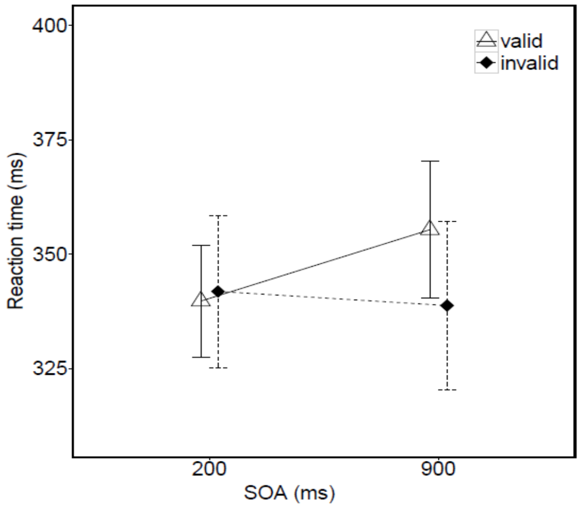
Model comparison of models with increasingly complex random-effects structures (*df.* the number of parameters in the model, involving the coefficients of the fixed effects of the model, AIC Akaike Information criterion, BIC Bayesian Information Criterion, Chi-Square log-likelihood test between successive models)

Models	*df*	AIC	BIC	log-likelihood	χ^2	$df_{\chi 2}$	*p*-value
M1x: RT ~ SOA * Validity + (1 | s)	6	20571	20604	-10280			
M2x: RT ~ SOA * Validity + (1 + SOA | s)	8	20535	20579	-10259	40.135	2	≪0.0001
M3x: RT ~ SOA * Validity + (1 + Validity | s)	8	20541	20585	-10262	0.000	0	1
M4x: RT ~ SOA * Validity + (1 + SOA + Validity | s)	11	20505	20566	-10242	41.646	3	≪0.0001

All models reported here converged and had random-effects that explained sufficient variance while showing reasonable levels of collinearity between factors ($r < 0.99$). Both AIC and BIC decrease with log-likelihood goodness-of-fit (Kliegl et al., 2011). As Model 4x has the lowest AIC and BIC, I selected Model 4x as the most parsimonious model among the models tested. Model 4x includes by-subject random intercepts and by-subject random slopes for SOA and Validity.

Fixed effects of RTs for SOA 200 and 900 ms

A statistically significant interaction between the SOA and Validity was found, χ^2 (1) = 12.56, $p < .001$. This interaction was further investigated by contrasts (χ^2 Test, *p*-value adjusted after Bonferroni). The results showed slightly faster but not significantly different responses (-3 ms) for targets cued at the same location (valid trials) compared to targets cued at the opposite location (invalid trials) for SOA 200 ms. Slower responses (+15 ms, p = 0.04) for valid trials compared to invalid trials for SOA 900 ms suggest an effect of IOR, see Figure 5.13.



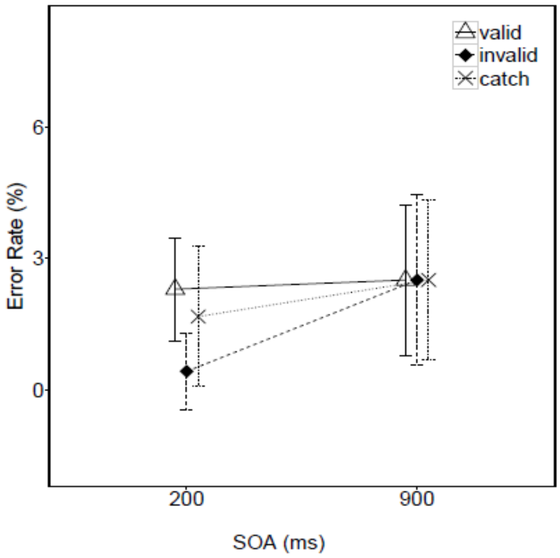


Figure 5.13. The results for SOAs of 200 and 900 ms in the single-cue condition in Exp. 4B. The line graph on the top panel shows the adjusted mean RTs (ms) returned from the corresponding the fitted model, Model 4x. Error bars represent the 95% confidence intervals of the adjusted means. The line graph on the bottom panel shows the ERs (%) averaged across subjects. Error bars denote ±1.96 SEM.

Random effects

Based on the model estimates, the individual variability of both intercept, SOA and Validity was computed. Figure 5.14 shows the conditional modes of the 20 participants, sorted by their intercept. 95% confidence intervals are also included, which are based on the estimation of the conditional modes and the conditional variances of the random effects. The results suggested that individual differences were more prominent for Intercepts (*SD* = 16.28) than for slopes for SOA (200 ms, *SD* = 8.06), Validity (valid, *SD* = 6.88), indicating that the individual variability in overall response times explained more variance than the individual variability of the effect of in the 200 ms SOA and valid condition. This is obviously shown in Figure 5.14, compared to all slopes, for the overall performances of individuals there are more participants whose confidence intervals do not touch the vertical line at zero (which represents group mean for intercepts and the mean of the fixed effect for slopes), deviating from the grand mean in further extents.

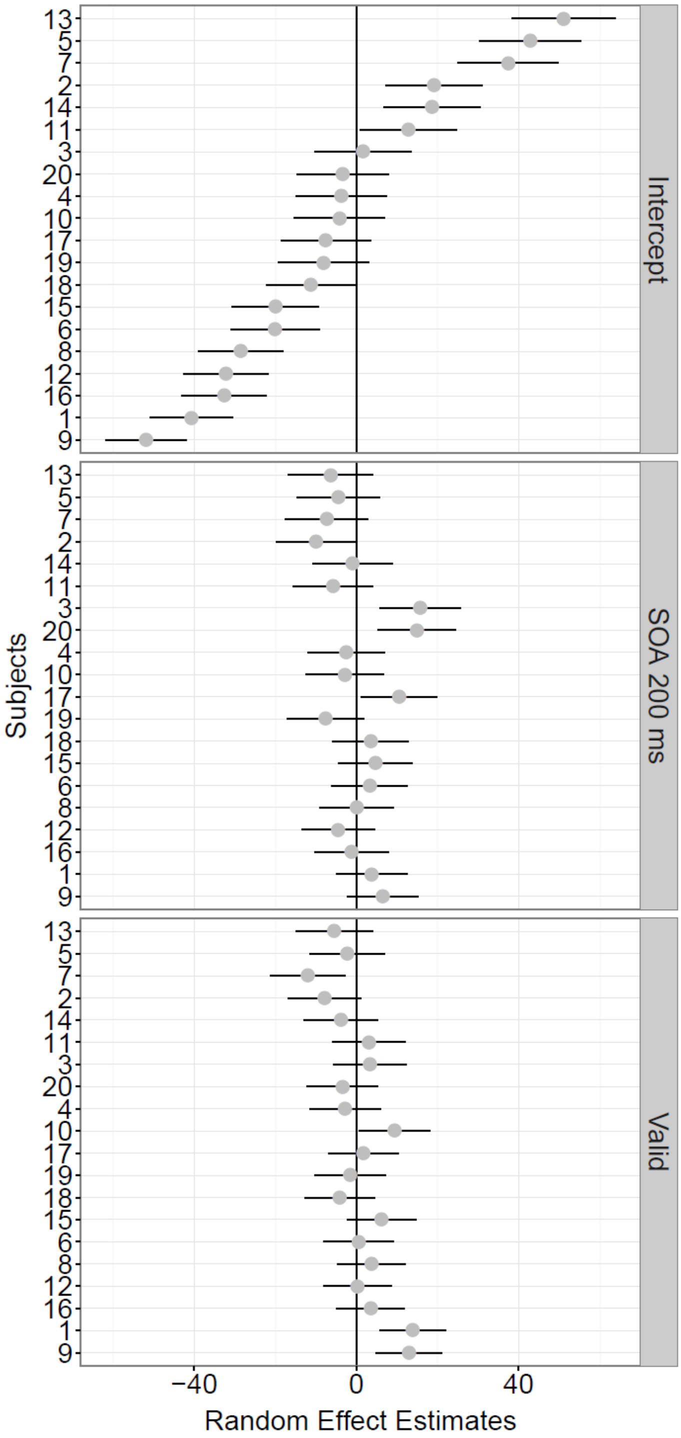


Figure 5.14. Visualization of the variance across subjects. Dotplots of random effects for each participant in Exp. 4B for the single cueing. The three plots show from top to bottom estimates of by-subject random intercepts, random slopes for SOA 200 ms, and random

slopes for the valid condition, respectively. The deviation coding system compares the mean of the dependent variable for one level against the overall mean of the dependent variable. For example, the fixed effect estimate for SOA 200 ms was calculated by comparing the mean of the SOA 200 ms against the overall mean of the SOA. The vertical lines centered on 0 represent the grand mean and the corresponding fixed effect estimate in each plot, 347.68 ms for the grand mean and a change of -3.70 ms for SOA 200 ms, and a change of 2.87 ms for the valid condition in the single-cue condition. Each dot represents a conditional mean and each horizontal error bar the corresponding 95% confidence interval. Participants are rank-ordered by the random intercepts in the single cueing condition. In short, the dotplots show that the individual variability in overall response times explained more variance than the individual variability of random slopes.

5.3.4 Discussion

In Exp. 4A facilitation was observed for the single cueing. However, facilitation was not found in Exp. 1 and 3A of this thesis which had similar experimental settings as Exp. 4A. A possible reason may be the increased temporal uncertainty of target onset in Exp. 4A caused by randomly intermixing trials with single and double cueing. The main aim of Exp. 4B was to examine this possibility by separating the trials with single and double cueing into different blocks. A second aim of Exp.4B was to examine whether the three characteristics of IOR for the double cueing observed in Exp. 4A would be affected.

The random effects of GLMM revealed that participants varied noticeably in their average RTs from the overall mean RT than other random effects, for both single and double cueing, as shown by the dotplots. The random effect of GLMM explained sufficient variance across subjects, which improved the estimates of fixed effects by controlling the inherent noise brought by different individuals.

With the single and double cueing separated between blocks, Exp. 4B replicated the result for single cueing that facilitation was still observed for the SOA 100 ms, and IOR was detected for the SOA 800 ms. However, the results for the double cueing differed from Exp. 4A. For SOA-D 100+800 ms, IOR was found in two-back and double-valid trials. IOR was not detected in one-back trials, which means IOR was not observed in more than one location, and the most recent cue location did not generate the strongest IOR. In addition, IOR in double valid trials were stronger than one-back trials but not stronger than two-back trials, which means no cumulative effect of IORs. If IORs cumulate at the same location, IOR in double valid trials should be stronger than IOR in both one-back and two-back trials.

For SOA-D 800+100 ms, IOR was found in two-back trials and facilitation was found in one-back trials. In other words, this result meant that Cue 1, which appeared a long time interval (900 ms) before the target, generated IOR, while Cue 2, which appeared a short time interval (100 ms) before the target, produced facilitation. These results were consistent with the single cueing that facilitation was found for SOA 100 ms and IOR for SOA 900 ms. In double valid trials, where Cue 1 and Cue 2 appear at the same location, no significant effect were found. This result replicated the studies by Visser and Barnes (2009) that facilitation counteracted IOR when these two effects appeared at the same location.

For SOA-D 100+100 ms, no significant effect was found in two-back trials whereas facilitation was found in one-back trials. In other words, Cue 1, which appeared 200 ms prior to the target onset, produced no significant effect, whereas Cue 2, which appeared 100 ms prior to the target onset, generated facilitation. These results were in line with the single cueing that no significant effect was found for SOA 200 ms whereas facilitation was found for SOA 100 ms. However, no significant effect was found in double valid trials.

5.4 General Discussion

Previous research has revealed three characteristics of IOR: (1) IOR occurred at multiple locations for cues that were presented successively at different locations in a double-cueing paradigm (e.g., Pratt & Chasteen, 2007; Visser & Barnes, 2009; 2010); (2) The most recently cued location in the one-back condition lead to the strongest IOR while earlier cued locations in the two-back condition resulted in weaker IOR (Danziger, Kingstone, & Snyder, 1998; Pratt & Chasteen, 2007); (3) When multiple cues appeared at the same location, IOR generated by each cue can accumulate (e.g., Pratt & Abrams, 1995; Dukewich & Boehnke, 2008). This has been labelled the “cumulative effect” of IOR (Visser & Barnes, 2009). In addition, IOR and facilitation generated by an earlier and later cue at the same location can counteract and result in no significant effect. However, it remains unclear whether facilitation also has the equivalent characteristics to IOR. More specifically, in a double-cueing paradigm, when cues appear successively, whether these cues can trigger facilitation at different cue locations, whether the most recent cue location generates the strongest facilitation, and whether facilitation accumulates at the same location (the cumulative effect). In Exp. 4A and 4B, I used a double cueing paradigm. Two successive cues were presented and SOA-D and cue location of both cues was systematically varied to study the characteristics of facilitation as well as IOR. I also included single-cueing conditions with SOA 100 and 800 ms in Exp. 4A and 4B and SOA 200 and 900 ms in Exp. 4B, in order to compare these conditions with double cueing conditions. The experimental settings of Exp. 4A and Exp. 4B were the same except for two aspects: Exp. 4B included

SOA 200 and 900 ms in addition to Exp. 4A. The second and more important difference was that in Exp. 4A single and double cueing were randomly intermixed in each block, whereas in Exp. 4B they were presented in separate blocks. Presenting the single- and double-cueing condition in separate blocks reduced temporal uncertainty about the target onset in observers. This manipulation allowed us to test whether facilitation and IOR as well as their characteristics were consistent when the single and double cueing conditions were intermixed and blocked. For the sake of simplicity, I will refer to the time interval between Cue 1 and target as the cue1-target interval and the time interval between Cue 2 and target as the cue2-target interval.

5.4.1 Facilitation and IOR

Presenting the single- and double- cueing condition in separate blocks in Exp. 4B changed the effects for double cueing but not for single cueing compared to results of Exp. 4A.

For the single cueing, both Exp. 4A and 4B observed facilitation for SOA 100 ms and IOR for SOA 800 ms, replicating the typical results (e.g., Posner & Cohen, 1984). These results indicated that a cue appearing 100 ms before the target onset facilitated target detection at the cue location but inhibited target detection at the cue location when the cue appeared 800 ms before the target onset. In one-back trials with SOA-D 100+100 and 800+100 ms for the double cueing, Cue 2 appeared 100 ms before the target onset, and targets location were preceded by one cue, which was similar to the single cueing with SOA 100 ms. However, facilitation of Cue 2 was only found in Exp. 4B, whereas no significant effects were found in Exp. 4A. In one-back trials with SOA-D 100+800 ms for the double cueing, Cue 2 appeared 800 ms before the target onset, which was similar to the single cueing with SOA 800 ms. However, Cue 2 generated significant IOR in Exp. 4A but non significant IOR in Exp 4B. In other words, presenting the single and double cueing in blocked trials, Cue 2 facilitated target detection and greatly reduced inhibition of target detection at the location of Cue 2 for the short and long cue2-target interval, respectively. In this sense, in Exp. 4B Cue 2 appeared to work effectively in attracting attention to the location of the cue, which lead to facilitation for the SOA-D 100+100 and 800+100 ms. In addition, attention might stay at the location of Cue 2 for a long period, which resulted in a small and non-significant IOR at the cue location for the SOA-D 100+800 ms. The effectiveness of Cue 2 in attracting attention in Exp. 4B but not in Exp. 4A may be explained by the expectation of observers for target onset after Cue 2 in Exp 4B, rather than the temporal uncertainty about target onset in Exp. 4A.

In each block of Exp. 4A, half of the targets appeared following a single cue (single cueing), while another half appeared after the second cue (double cueing). However, in each double cueing block in Exp. 4B, targets would only appear after Cue 2. As only half of the targets appeared following Cue 2 in Exp. 4A but all targets appeared after Cue 2 in Exp. 4B, the latter one appeared to be more important in terms of expecting targets for making response. Therefore, Cue 2 in Exp. 4B worked more effectively than Cue 2 in Exp. 4A in terms of attracting attention, or more specifically, attracting processing resources according to Visser and Barnes (2009). This resulted in facilitation of target detection for the short cue2-target interval and only minor IOR for the long cue2-target interval at the location of Cue 2. The studies by Visser and Barnes (2010) showed that the IOR in one-back trials, however, remained unchanged no matter whether the double cueing was presented with or without single cueing in the same block. Their result, although appeared to be different from the result of the present experiment, is not contradictory to the results of the present experiments (Exp. 4A and 4B) due to the differences in time interval between the present and their experiment. Specifically, their shortest time interval between cues was 200 ms, which was 100 ms in the present experiments, and their result showed that IOR declined as the time interval between cues decreased. Therefore, when time interval between cues was 100 ms, IOR might be reduced to a non-significant effect as in their experiment when the double cueing blocked with the single cueing. In short, expectancy of target onset of cues could possibly increase the effectiveness of attracting attention to the cue location.

The IOR remained stable in two-back trials for SOA-D 100+800 and 800+100 ms no matter whether the double cueing was presented with or without single cueing in the same block. This is consistent with the results in the studies by Visser and Barnes (2010).

In summary, for SOA-D 100+800 ms, Exp. 4A replicated previous finding that IOR was found at multiple cue location locations (e.g., Pratt & Chasteen, 2007; Visser & Barnes, 2009; 2010), that the most recently cued location lead to the strongest IOR while earlier cued locations lead to weaker IOR (Danziger, Kingstone, & Snyder, 1998; Pratt & Chasteen, 2007). However, in Exp. 4B IOR was observed in two-back but not in one-back trials which means that IOR was not observed at two locations at the same time. For SOA-D 800+100 ms, IOR was observed in two-back trials in both Exp. 4A and Exp. 4B. Facilitation was observed in one-back trials in Exp. 4B but not in Exp. 4A. For SOA-D 100+100 ms, facilitation was observed in one-back trials in Exp. 4B but not in Exp. 4A. The changes in effects between Exp. 4A and Exp. 4B might be due to expectancy of target onset after Cue 2 in observers.

5.4.2 The Cumulative Effect of IOR

For SOA-D 800+100 ms in Exp. 4B, IOR was observed in two-back trials and facilitation was observed in one-back trials, it meant that Cue 1 generated IOR and Cue 2 produced facilitation. When two cues appear at the same location, no significant effect was found, which replicated previous finding that when cues appear at the same location the IOR by Cue 1 was counteracted by the following facilitation by Cue 2 and resulted in no significant effect at the location (Visser & Barnes, 2009).

For SOA-D 100+800 ms in both Exp. 4A and 4B, the magnitude of IOR in double valid trials were not significantly greater than both the IOR in one-back and two-back trials (see also Visser & Barnes, 2009; 2010). Nevertheless, for both Exp. 4A and 4B, the magnitude of IOR in double valid trials was about the sum of IOR in one-back and two-back trials, which was 23 ms for double valid trials, 17 ms for one-back trials, and 10 ms for two-back trials in Exp. 4A, and 15, 4, and 9 ms in Exp. 4B. In other words, the magnitude of IOR accumulated, despite that IOR in double valid trials were not always significantly different from IOR in both one-back and two-back trials. The reason for the non-significant cumulative effect might be due to the interval between the onset of the two cues (100 ms), which was at least two times shorter compared to previous researches where a cumulative effect was observed. For example, the interval between the onset of the two cues was 200 ms in the studies by Visser and Barnes (2010) and 360 ms in the studies by Pratt and Abrams (1995). Dukewich and Boehnke (2008) suggested that IOR might due to visual adaptation and habituation. Visual adaptation is that the visual system alters its responsiveness according to recent stimuli record, often by reducing its responses repeated stimuli (Clifford et. al, 2007). Habituation is a non-associative learning mechanism leading an organism to stop respond to repetitive irrelevant stimulus (Thompson & Spencer, 1966). Based on the theory of adaptation and habituation, the more frequent cues appear at the same location, the more the visual response to the target will be reduced, resulting in slower initiations to respond to targets, hence greater IOR. As the rate of stimulus presentation modulates the effect of adaptation (Thompson & Spencer, 1966), the time interval between cues affects the magnitude of IOR generated by cues at a single location. Therefore, the reason that no cumulative effects were observed when cues appeared at the same location in Exp. 4A and

Exp. 4B might due to the time interval which was at least two times shorter than the time interval in previous experiments. Future experiments may conduct to investigate this potential reason.

5.4.3 Characteristics of Facilitation

Although it has been reported that facilitation can be observed for SOAs of 200 ms (e.g., Rafal et al., 1991; Exp. 2 in Berger et al., 1999) and more than 200 ms (e.g., Berger et al., 1999), Exp. 4B did not find facilitation for SOAs of 200 ms. No facilitation was observed in Exp. 4A and 4B, for SOA-D 100+100 ms; facilitation was not observed at multiple location as no significant effect was found in two-back trials, which were consistent with the reference SOA 200 ms for the single cueing. To investigate whether facilitation can appear at multiple location, whether the most recent cue produced the strongest facilitation, and whether the facilitation at the same location accumulate, future work should choose shorter intervals between Cue 1 and target such as 100 ms. In addition, even if the most recent cue does generate a stronger facilitation than facilitation generated by earlier cues, this difference does not necessarily reflect the occurrence of the most recent cue. This is because facilitation decays quickly as the SOA gets longer (Samuel & Kat, 2003). Therefore, a more sophisticated design is needed.

Chapter 6 General Discussion

In the Posner paradigm (Posner, 1980), participants respond to a visual target following a cue in the periphery. The cue affects participants' responses to targets even when it does not provide any reliable spatial (e.g., Bayliss et al., 2005; Colzato et al, 2012) or temporal information (Tipper & Kingston, 2005) of the target. The effect of the cue on responses to targets varies depending on the temporal and spatial relationship between the cue and target. Responses to targets at the cue location are slower for short SOAs (facilitation), but faster for long SOAs (IOR) than the location not preceded by cues. Facilitation and IOR are two characteristic effects that emerge in the Posner paradigm (Posner, 1980).

It has been suggested that these two effects are related to attention triggered by cueing (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). In particular, a cue triggers orientation of attention to the cue location shortly after the cue onset and speeds up target detection at the cue location relative to other location(s), resulting in facilitation (Posner & Cohen, 1984). Attention then shifts away after a longer interval following the cue onset and inhibits from returning to previous cued locations, resulting in slower responses to targets at the cue location compared to other locations. This effect has been labelled as IOR (Posner, Rafal, Choate, & Vaughan, 1985).

Ever since its debut, the Posner cueing paradigm (Posner, 1980) has become seminal for studying of attention. Many variants of the classic paradigm have been developed to study attention. For example, an arrow cue was presented at fixation instead of peripheral cues to study the effect of endogenous attention (e.g., Mahadevan, Bedell, & Stevenson, 2018; Seiss, Kiss & Eimer, 2009); saccadic eye movements were included to study overt attention (e.g., Hooge, Over, van Wezel & Frens, 2005; Machado & Rafal, 2004). Among these the covert orienting of visual attention task (COVAT) investigates covert and exogenous attention. In addition to the study of attention, the variants of Posner paradigm were also designed to study facilitation and IOR, including their underlying mechanism and characteristics. Theoretical accounts have been proposed to explain the mechanism of facilitation and IOR, such as the sensory account (e.g., Tassinari et al., 1994) for facilitation and the motor bias account (Collie, Maruff, Yucel, Danckert, & Currie, 2000) for IOR. These accounts were put forward in addition to the early attentional account, because the attentional account failed to explain the phenomenon in later studies, that is, unlike the robust IOR, facilitation was not always observed (e.g., Prime et al., 2006; Riggio, Bello, & Umiltà, 1998), although facilitation and IOR were supposed to describe a biphasic effect (Posner & Cohen, 1984; Rafal & Henik, 1994).

Previous research has reported that the magnitude of facilitation and IOR was affected by physical characteristics of cues (e.g., Lambert & Hockey, 1991; Pratt, Hillis, & Gold, 2001) and target (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996) on the COVAT. In the present thesis I studied facilitation and IOR by manipulating physical characteristics of the stimuli (cue and/ or target) and the number of cues, in order to demonstrate the effect of sensory processing on facilitation and IOR.

6.1 Summaries of Results

In Exp. 1 I examined the cue–target discriminability by manipulating the novelty of cues and targets. The cues and targets in Exp. 1 were either novel or repetitive and both the novel cues and targets never repeated in trials and blocks. Four blocks were included in Exp.1: repetitive cues and targets, repetitive cues and novel targets, novel cues and repetitive targets, and novel cues and targets. I observed IOR for the long SOA but no facilitation for the short SOA in all the conditions tested, regardless of the novelty of cues or targets. The cue–target discriminability did not affect the magnitude of IOR, which was consistent with the conclusion suggested by Pratt et al. (2001). The effect of cue-target discriminability did not affect the occurrence of facilitation.

In Exp. 2 I examined the effect of presenting onset and offset cues on facilitation and IOR in different sequences of appearing and disappearing cues. In short, I investigated the difference between on-off and off-on cues on facilitation and IOR. I found IOR for long SOA but no facilitation for short SOA in the condition of on-off cueing. I found the opposite results in the condition of off-on cueing, that is, facilitation was observed for short SOA but no IOR for long SOA.

Exp. 2 also included a no-cue condition, which served as a reference for the two conditions with cueing. Comparing the response times of the valid and invalid condition against the no-cue condition indicated the following results. Firstly, in the on-off cue condition, although for the short SOA the cue did not trigger facilitation as expected, the cueing slowed down target detection regardless of the valid or invalid location. The delay on target detection caused by the cue was short-lived as it was found for the short SOA but not for the long SOA. Secondly, IOR was not caused by inhibition to the previously attended location (Posner, Rafal, Choate, & Vaughan, 1985), but rather by a bias to inspect the target at the new location (McCarley et al., 2003). Thirdly, the sequence for the grouped onset and offset cues influence the effects of grouped cues on target detection. Compared to the effects of on-off cues, the effects of off-on cues on target detection were more short-lived, because in the off-on cue condition responses in trials with valid and invalid cueing were both not statistically different from the no-cue condition for the long SOA. Nevertheless, the short-lived effects of off-on cues were able to capture attention.

In Exp. 3A I examined the effects of the size of the cue and target on facilitation and IOR. Exp. 3A included a set of small or a set of large cues and targets in separate blocks. I found no facilitation for the short SOA but observed IOR for the long SOA, for both small and large stimuli. In addition, in the condition with small stimuli I observed IOR for the short SOA. The size of cue and target did not affect the magnitude of the IOR.

In Exp. 3B I examined the effect of changes in cue size on facilitation and IOR. The cues were either static or dynamic. Similar to Exp. 3A, cues in the static cue condition were either small or large while cues in the motion condition were divided into two dynamic conditions, changing from small to large cues or from large to small cues. The motion cue mimicked the dynamic process of adjusting the “zoom lens” of attention. I found no facilitation but observed IOR in all conditions. When the cue was static, the IOR in the small condition was greater than IOR in the large cue condition. The presentation time of the cue in the condition of static cue in Exp. 3B was about 3 times longer than the cue duration in Exp. 3A and the condition of motion cue in Exp. 3B. The reason why the effect of stimuli size on IOR was only found for the static cue in Exp. 3B may be the longer presentation of cues. This may have enhanced the effect of cue size on IOR.

In Exp. 4A and Exp. 4B I used a double-cueing paradigm. By systematically varying SOA-D and the relative location between the cue and target I studied the characteristics of facilitation as well as IOR. The single and double cueing was intermixed in Exp. 4A but blocked in Exp. 4B. I examined: (1) whether IOR occurred at multiple locations for cues that were presented successively at different locations in a double-cueing paradigm; (2) whether the most recently cued location in the one-back condition lead to the strongest IOR while earlier cued locations in the two-back condition resulted in weaker IOR; (3) whether IOR generated by each cue can accumulate when multiple cues appear at the same location; (4) whether facilitation has similar characteristics as IOR in a double-cueing paradigm. I also studied single-cueing conditions with SOA 100 and 800 ms in Exp. 4A and 4B and SOA

200 and 900 ms in Exp. 4B, in order to compare these control conditions with double-cueing conditions.

For single cueing, facilitation was found for SOA 100 ms in both Exp. 4A and 4B, while IOR was found for SOA 800 in both Exp. 4A and 4B and IOR was found for SOA 900 ms in Exp. 4B. For double cueing, IOR occurred at multiple cue locations in Exp. 4A, was stronger at the most recently cued location, and accumulated when two cues appeared at the same location. These results were consistent with previous studies (e.g., Visser & Barnes, 2009, 2010). However, facilitation did not occur for double cueing. In Exp. 4B, IOR was found only at locations preceded by the first cue and non-significant IOR at the location preceded by the second cue when targets appeared after a long interval following two cues (the condition of SOA-D 100+800 ms). For SOA-D 800+100 ms, I found the first cue generated IOR while the second cue produced facilitation when cues were at different locations. When cues appeared at the same location in succession, no significant RT effect were found at the cued location, indicating that IOR counteracted facilitation. This is consistent with results from previous studies (Visser & Barnes, 2009). For SOA-D 100+100 ms, significant facilitation was found at the most recently cued location and non-significant IOR was found at the earlier cued location. Nevertheless, when two cues appeared at the same location for SOA-D 100+100 ms, the magnitude of facilitation was about the sum of facilitation and non-significant IOR generated respectively by the first and second cue when the cues appeared at different locations. Similarly, when two cues appeared at the same locations for SOA-D 100+800 ms, the magnitude of IOR was about the sum of IOR generated by the first and second cue when cues appeared at different locations. Compared to the Exp. 4A, in the double-cueing condition of Exp. 4B the second cue worked more effectively in terms of attracting attention. I speculate that expectancy of target onset of cues may increase the effectiveness of attracting attention to the cue location.

6.2 The Absence and Presence of Facilitation

The short SOA in Exp. 1, 3A, and the the single-cueing condition of 4A, and 4B was 100 ms, while in Exp. 2 the short SOA was 80 ms and in Exp. 3B it was 150 ms. Either of these SOAs should be short enough to generate facilitation (Collie, et. al, 2000; Chica, et al., 2014). However, facilitation was only found in Exp. 2 with off-on cues and in Exp. 4A and 4B for single cueing. Besides these conditions, facilitation was absent in Exp. 1 for the short SOA, regardless of the discriminability between cue and target. It was also absent in Exp. 2

for on-off cues, in Exp. 3A regardless of the size of cue and target, and in Exp. 3B regardless of the cue size and whether or not the cue was dynamic.

In short, facilitation was found in the off-on cue condition in Exp. 2, the single-cueing condition in Exp. 4A and 4B but was absent in Exp. 1, Exp. 3A, 3B, and the on-off cue condition in Exp. 2. Although facilitation was absent in Exp. 1, Exp. 3A, 3B, and the on-off cue condition in Exp. 2, the cue may still affect target detection, as indicated by results of the on-off cue condition of Exp. 2. That is, the occurrence of a cue delayed target detection regardless of the relative location of cue and target.

6.2.1 Factors Regarding Facilitation

The experimental tasks in this thesis were detection tasks. The absence of facilitation for short SOAs in the present experiments are consistent with research suggesting that facilitation is more difficult to observe than the relatively robust effect of IOR (see, e.g., Collie, Maruff, Yucel, Danckert, & Currie, 2000; Mele, Savazzi, Marzi, & Berlucchi, 2008; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1995). In addition, detection tasks are less likely to induce facilitation compared to discrimination tasks (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999; Lupiáñez, Ruz, Funes, & Milliken, 2007). Lupiáñez and colleagues have consistently shown that facilitation is stronger in discrimination than in detection tasks.

The detection tasks used in this thesis did not benefit facilitation but the following experimental settings of the tasks did help facilitation. Firstly, a short cue-target SOA of less than 250 ms is also favourable for the facilitation to take place (Maylor, 1985; Maylor & Hockey, 1987; Posner & Cohen, 1984). Secondly, a fixation cue was not included in any of the experiments in this thesis. In some studies, a fixation cue at the centre was presented after the cues in the periphery in order to orient attention back to the central location (e.g., Posner & Cohen, 1984; Prime et al., 2006). According to the attentional orientation account of IOR, a central fixation cue helps remove attention from the cue locations in the periphery and thus promotes IOR, but may eliminate facilitation. Thirdly, there were only two possible target locations in my experiments. It has been suggested that for a larger number of target locations in a simple detection task with exogenous cueing, the benefit of the exogenous cueing on reaction times for short SOA was reversed into a cost (e.g., Chen, Moore, & Mordkoff, 2008; Mordkoff, Halterman & Chen, 2008). In other words, IOR instead of facilitation was observed for short SOAs when the number of display locations was large.

Therefore, the display of only two target locations used in this thesis helped facilitation. In addition, except for Exp. 2, all the cues and targets had not spatial overlap. No spatial overlap between the cue and target is also advantageous for facilitation (e.g., McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001).

Indeed, facilitation is affected by many factors. In the following sections, I will compare the results between the experiments in this thesis to investigate potential factors that affect facilitation.

6.2.2 On-off cues

The results of Exp. 1, 3A, 3B and the on-off cue condition in Exp. 2 are quite similar as they did not show facilitation for the short SOA but IOR for the long SOA. These experiments were not only very similar in terms of their results, but also in terms of their experimental settings. In particular, although I manipulated physical characteristics such as novelty and size, the experiments all employed single cueing and on-off cues. For the sake of simplicity, I will refer to them as Single on-off Exps (Exp. 1, 3A, 3B and the on-off cue condition in Exp. 2).

6.2.2.1 Temporal Overlap

It has been suggested that a cue which overlaps temporally with the target (see Figure 6.1) helps facilitation but not IOR (Collie et al., 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). In other words, the cue is displayed until the target disappears. Specifically, Collie et al., (2000) reported that facilitation was observed after a short SOA of 150 ms and when the cue display overlapped in time with the target. If cues overlap temporally with targets in Single on-off Exps, facilitation is more likely to occur. However, studies also showed that a temporal overlap between the cue and target was not necessary to observe facilitation as facilitation was found in detection tasks with or without temporal overlap between the cue and target (Berger, Dori, & Henik, 1999; McAuliffe & Pratt, 2005). In addition, even though cue and target overlapped temporally, facilitation could be absent (e.g., see Experiment 2, 3, and 4 in Tassinari, et al., 1994). Thus, it is questionable whether a lack of temporal overlap between cue and target is the cause for the absence of facilitation in Single on-off Exps.

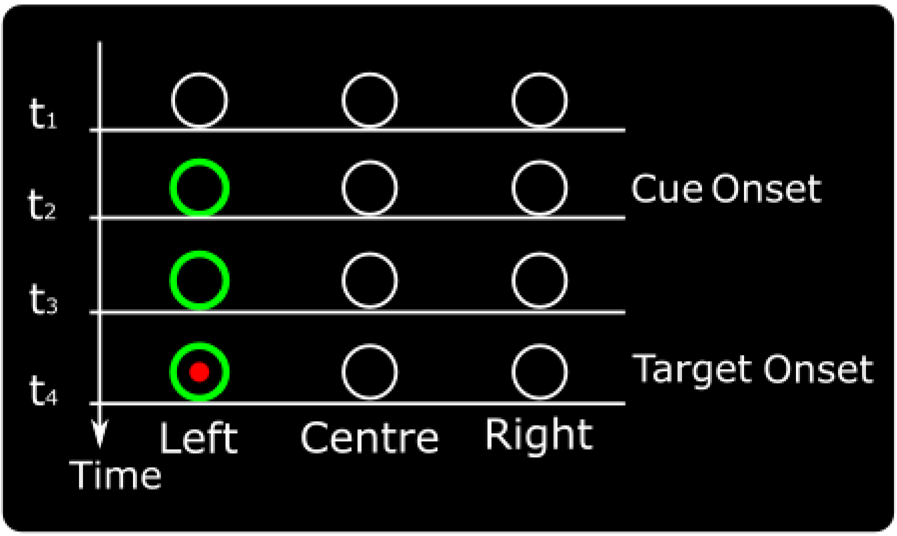


Figure 6.1. An example of the design that cues temporally overlapping targets. This figure is an illustration of the design of the condition with temporally overlapping cue in Maruff et al. (1999), Exp. 3. Placeholders are white circles in the periphery; The cue is a green circle; the target is a filled red circle. The onset of cue is at t_2 and the onset of target is at t_4.

However, the effect of temporal overlap becomes clearer if we take the duration of the target into account. In their Exp. 3, Maruff, et al. (1999) investigated the effect of the duration of target and the temporal overlap between the cue and target on facilitation and IOR by using a detection task with two peripheral target locations, see Figure 6.1. In their Exp. 3 the target duration also modulates facilitation and IOR, similar to the temporal overlap between the cue and target. When the cue did not overlap in time with the target, for the short SOA IOR and no significant effect was found with brief and long targets, respectively, while for the long SOA, IOR was found with both brief and long targets. When the cue overlapped in time with the target, for the short and long SOA no significant effect found with either brief or long targets, except for facilitation for the short SOA with long targets, see Figure 6.2. These results explain the absence of facilitation for short SOAs, regardless of the temporal overlap of the cue with the target in the studies by Tassinari et al. (1994) where the target duration was as short as 16 ms in all four experiments.

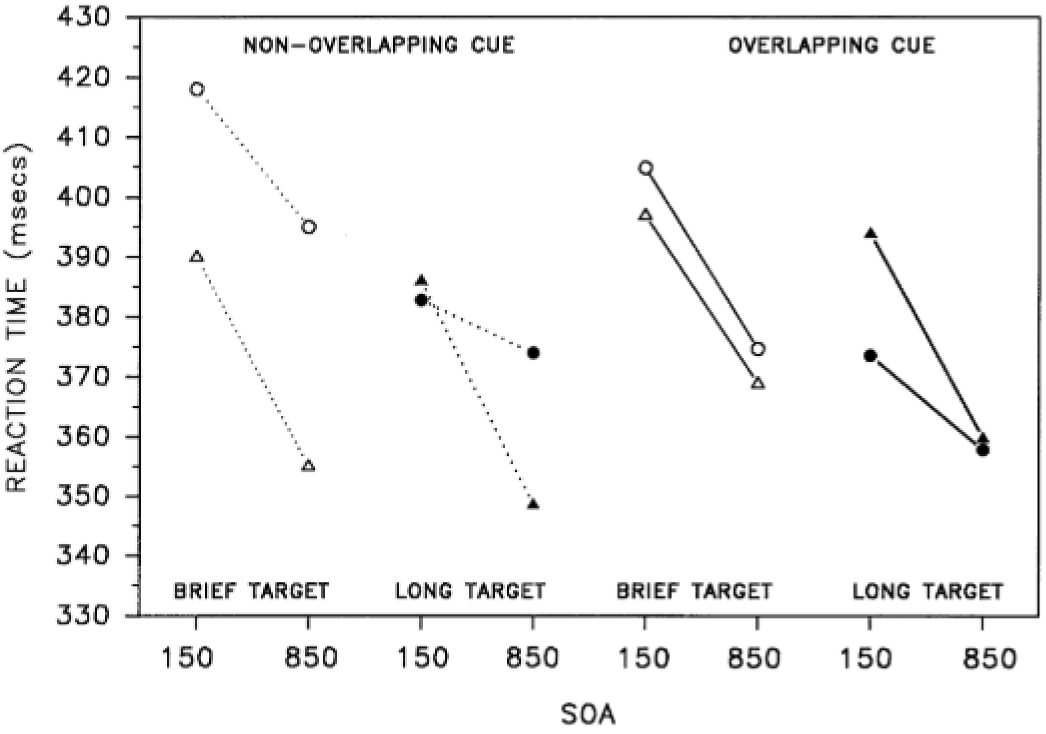


Figure 6.2. This figure is reproduced from Maruff, Yucel, Danckert, Stuart, and Currie (1999), Fig. 5, p. 739. In their Experiment 3, they modulated the temporal overlap between the cue and target (with or without temporal overlap) and target duration (brief or long). The brief target duration was 50 ms while for the long target duration the target remained on screen until the participant made a response. They used a detection task with two target locations in Experiment 3 and measured reaction times.

The maximum response times in the studies by Maruff et al. (1999) was 5 seconds, which means that the long cue in their experiments could be as long as 5 seconds. The maximum target duration in all my experiments was 500 ms (Exp. 3A), 750 ms (Exp. 1, 3B, 4A, and 4B), or 1000 ms (Exp. 2), which is at least 4 seconds shorter than the maximum duration of the long target in the studies by Maruff et al. (1999). Nevertheless, as shown in Figure 6.2, the maximum mean responses times in their studies were less than 430 ms, which means that the maximum duration of the long target perceived by participants was less than 430 ms. In this sense, a long target duration does not actually mean only the maximum duration a target could be but, more importantly, it means that the target duration should be long enough that a target could outlast the participants' maximum responses time of correct responses. In all the experiments of this thesis, the target durations outlasted the maximum mean reaction times of correct trials in each condition. It is true that any reaction time longer than the target duration was excluded from the calculation of the mean reaction times so mean reaction times can only be shorter than the target duration. The error rates for the situation that responses were given after the target duration were lower than 2% in each of my experiments. So the reaction times of almost all participants in my experiments were shorter than the target presentation and thus the targets in my experiments could be considered as equivalent to the ‘long targets’ in the studies by Maruff et al. (1999). The results of my experiments are therefore more comparable with their results in the long-target conditions.

Single on-off Exps had temporally non-overlapping cues and long target durations, replicating the condition of non-overlapping cues and long target durations in Exp. 3 of Maruff et al. (1999). Correspondingly, this condition had the same pattern of reaction times for the short and long SOA as the Single on-off Exps. That is, no facilitation was observed for the short SOA but IOR was observed for the long SOA. However, when the cue overlapped temporally with the target, Maruff et al. (1999) also found facilitation for the short SOA. Therefore, considering the similarity of results and experimental settings between Single on-off Exps and their Experiment 3, if the cue in Single on-off Exps overlaps in time with the target, it is very likely to trigger facilitation. Even so, it still does not explain why facilitation is absent from experiments with on-off cues in the Single on-off Exps, especially considering that experiments with similar experimental settings observed facilitation for the short SOA. For example, in their Exp. 1, McAuliffe and Pratt (2005) also used a paradigm with detection tasks and two peripheral target locations, cues without spatial and temporal overlap with the targets, the same features of stimuli of cues (empty square) and targets (filled-in square). These experimental settings also apply to Exp. 4A and 4B in this thesis, which also found facilitation for the short SOA in the single-cueing condition.

A possible explanation that accounts for the facilitation in Exp. 4A and 4B but not in Single on-off Exps is the uncertainty of the target onset for short SOA. Although Exp. 4A and 4B had no temporal overlap between the cue and target in a trial, the second cue overlapped in time with the expectation of target presentations across trials. More specifically, except for the target in trials with single-cueing, the second cue might appear 100 ms after the onset of Cue 1, with a greater chance for another cue (4/7) than for a target (3/7), marked out in Red in Figure 6.3. Thus, the expectation of a cue and target were temporally overlapping at 100 ms after the onset of the first cue.

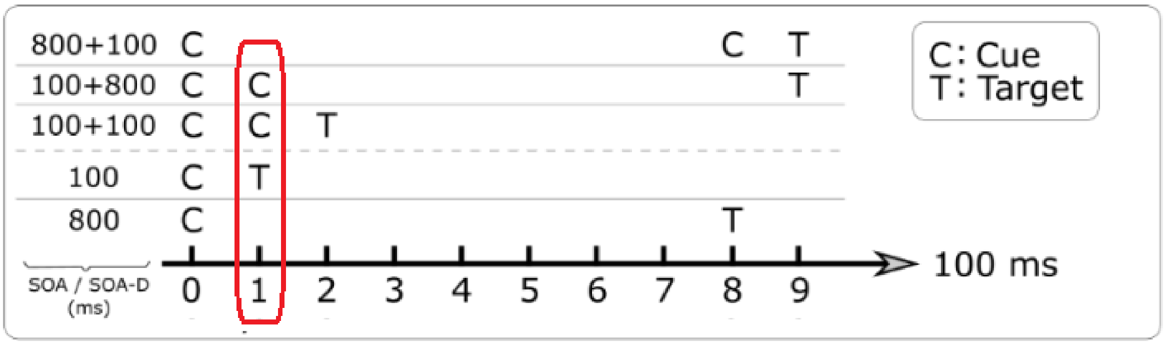


Figure 6.3. Illustration of the procedure for single and double cueing in Exp. 4A and 4B. On the x-axis, events are aligned to the onset of Cue 1 at 0 ms. For example, the first row shows that for SOA-D 800+100 ms, Cue 2 appeared at 800 ms from the onset of Cue 1 and the target appears 900 ms from the onset of Cue 1.

Trials in Single on-off Exps had only a single cue, therefore participants knew for certain that the stimulus after the cue must be a target. Thus, participants could detect only the emergence of a stimulus, without further processing its location in Single on-off Exps. Therefore, mean reaction times for target detection were similar regardless of the relative location of cue and target (valid or invalid) for the short SOA. However, for Exp. 4A and 4B, because either a cue or a target would occur 100 ms after the onset of the cue which followed the trial onset, participants would need to discriminate between a cue and a target. Therefore, except for knowing the occurrence of a stimuli, participants also needed to look into the specific location of the target for the discrimination between a cue and a target. Previous research has emphasised the importance of the effect of a cue on facilitation, especially in detection tasks with non-informative cues. For example, according to the attentional orientation account facilitation is due to cues that trigger attentional orientation to the cue location (Posner & Cohen, 1984), and in the sensory account facilitation is due to the summation of physical energies of the cue and target at the cue location when they are temporally overlapping (Tassinari, et al., 1994). In addition to the importance of the cue, I propose that the processing of the target location is as important for the occurence of facilitation in a detection task. This proposal is consistent with the finding that facilitation is stronger in discrimination than in detection tasks (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999; Lupiáñez, Ruz, Funes, & Milliken, 2007). For example, for the short SOA in the single-cueing condition in Exp. 4A, distinguishing a target from a cue is similar to a discrimination task and may therefore favour facilitation.

In Exp. 4B, the single-cueing and double-cueing trials were presented in separate blocks of trials. In this case, the uncertainty of the observer about the target onset in single-cueing blocks should be the same as in Single on-off Exps, where no facilitation was found.

However, facilitation was observed in the single-cueing condition of Exp. 4B. There are two possible explanations. First, the account in terms of temporal overlap between trials may be incorrect. Second, considering that blocks of single and double cueing alternated in Exp. 4B, this might still create expectations and therefore temporal overlap between the cue and target as in Exp. 4A. In other words, it is possible that the temporal overlap between the cue and target can occur not only between trials but also between blocks. This possibility can be tested in a further experiment that separates the block of single and double cueing, without alternating between blocks of single and double cueing trials. This would mean that participants perform in the blocks of single and double cueing in separate sessions.

Note that this explanation applies to facilitation but not to IOR. IOR was consistently observed in Single on-off Exps, suggesting that IOR is the result of a different process than facilitation, otherwise IOR would not appear according to the account of uncertainty of the target onset. The idea that facilitation and IOR have different processes has been put forward in previous research (e.g., McAuliffe & Pratt, 2005; Collie, et al., 2000). For example, McAuliffe and Pratt (2005) suggested that facilitation is produced by a shift of attention to the cued peripheral location, whereas IOR is generated by the onset of the peripheral cue. Despite this, IOR normally occurs for the long SOA because IOR is masked by facilitation for short SOA.

6.2.3 Off-on Cues

Facilitation was found for off-on cues whereas no facilitation was observed in Single on-off Exps. A major difference was the cue type, specifically, the sequence of the grouped onset and offset cues. According to the attentional orientation account, which was proposed as an explanation for facilitation (Posner & Cohen, 1984), facilitation is the result of attentional orientation to the cued location. Based on this account, a rather straightforward explanation is that off-on cues work more effectively than on-off cues in terms of attracting attention to the cue location, considering that most of the other experimental settings were rather similar to the on-off cue condition.

The off-on cue was more effective than the on-off cue, and, furthermore, it worked as effective as a cue overlapping in time with the target, which produced long facilitation that can even mask inhibition for long SOA (Collie et al., 2000; Maruff, Yucel, Danckert, Stuart, & Currie, 1999). This has been explained by attention being oriented to the cue location, triggered by a cue (Posner & Cohen, 1984). A long cue can hold the attention at the cue location before attention is disengaged from the cue location (Collie et al., 2000; McAuliffe & Pratt, 2005). An abrupt onset of the peripheral cue initiates a motor bias against responses to targets appearing in the same location (Klein & Taylor, 1994) and inhibition starts 150 ms after the onset of the cue (Collie et al., 2000). However, after the inhibition starts, the inhibition is masked by the facilitation (Collie et al., 2000; McAuliffe & Pratt, 2005). The longer the cue duration, the longer the facilitation, and the more inhibition is masked (McAuliffe & Pratt, 2005). As a result, facilitation is observed for short SOA and a small or no IOR is observed for long SOA. An example of this result is in the Exp. 3 of the study by Maruff, et al. (1999), see the condition of overlapping cue and long target in figure 6.2. A similar result emerged in the off-on condition in Exp. 2. Note that although there was no temporal overlap between the cue and target in Exp. 2, see figure 6.4, the off-on cue worked as effectively as the overlapping cue to hold attention, The off-on cue can hold attention until the long SOA and masked the IOR, resulting in the absence of IOR. This is probably the reason for the absence of IOR in the off-on cue condition with long SOA of Exp. 2.

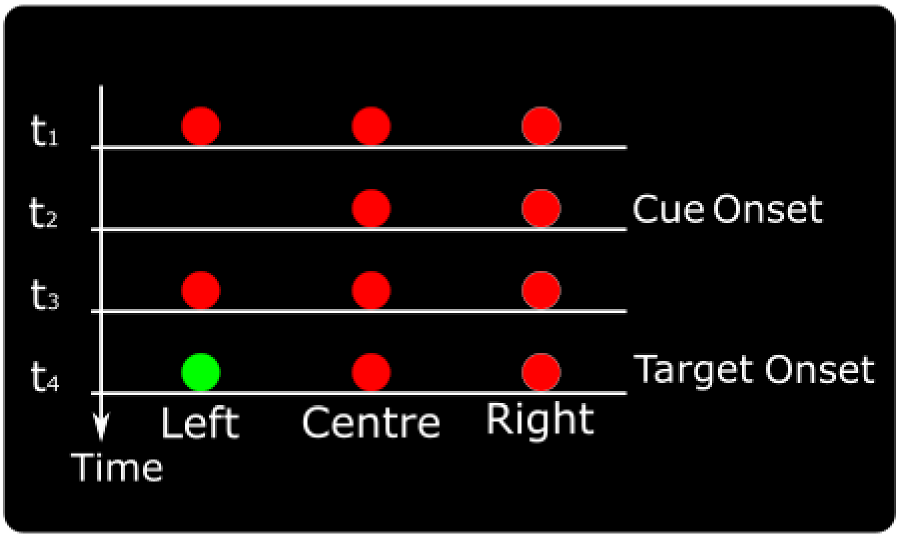


Figure 6.4. The graph is the illustration of the design of the off-on cue condition in Exp. 2 in this thesis. Placeholders are peripheral red circles presented on the left and right in the periphery. The onset of the off-on cue is at t_2 (the offset of the red circle) and the onset of target is at t_4. The cue is the disappearance of one peripheral red circle followed by its appearance. The target is a peripheral green filled circle.

6.2.4 Double cueing

Compared to Exp. 4A, Cue 2 in Exp. 4B appeared to work effectively in attracting attention to the location of the cue, leading to facilitation. In addition, attention might have stayed at the location of Cue 2 for a long period, resulting in a small and non-significant IOR at the cue location. The effectiveness of Cue 2 in attracting attention in Exp. 4B but not in Exp. 4A may be explained by the expectation of the target after Cue 2 in the observers of Exp 4B. More specifically, compared to Cue 2 in Exp. 4A, Cue 2 in Exp. 4B appeared to be more important in terms of target expectation and for making a response. Therefore, Cue 2 in Exp. 4B worked more effectively than Cue 2 in Exp. 4A in terms of attracting attention, or more specifically, attracting processing resources according to Visser and Barnes (2009).

6.3 The Absence and Presence of IOR

While facilitation is absent in Single On-off Exps, IOR was consistently present in Single on-off Exps. This is in line with literature on detection tasks where, contrary to facilitation which is not always found, IOR is more easy to observe (see, e.g., Collie, Maruff, Yucel, Danckert, & Currie, 2000; Mele, Savazzi, Marzi, & Berlucchi, 2008; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1995).

6.3.1 On-off Cue

IOR was consistently found in Single On-off Exps. As indicated by the no-cue condition in Exp. 2, IOR is a bias to inspect the target at the new location, which supports the account proposed by McCarley et al. (2003). In the on-off cue condition in Exp. 2, the responses to the invalid location were faster than responses to the no-cue location. Therefore, IOR was not caused by inhibition to the previously attended location (Posner, Rafal, Choate, & Vaughan, 1985), but rather by a bias to inspect the target at the new location (McCarley et al., 2003).

6.3.2 Off-on cue

The robust IOR was consistently found in all the experiments with single cueing in this thesis, except for the off-on cue condition in Exp. 2. One possibility has been discussed above that facilitation generated by the off-on cue was so long that it masked the IOR, which is assumed to initiate quickly after the cue onset (McAuliffe & Pratt, 2005). Another possibility is that the IOR was eliminated by the appearance of red circle (as shown at t_3 in the right graph of Figure 6.4) following the offset of red circle. Note that in the invalid and no-cue condition, the target location was not preceded by cues and remained the red circle before the target appeared. As a result, the response times for valid and no-cue trial were statistically similar for both short and long SOA. As for the valid condition, after the appearance of the red circle, both the left and right location in the periphery became the same since both locations were occupied by red circles. As a result, the response times became almost the same as the valid, invalid, and no-cue condition (see figure 6.5). It has been suggested that inhibitory tags are attached to the location that has been searched and found no target (Klein, 2000). Therefore, in the off-on cue condition of Exp. 2, after the offset of red circle, an inhibitory tag might be attached to this location. However, the inhibitory tag was probably removed by the later appearance of the red cue at the same location, resulting in no inhibition at this location. Therefore, the robust IOR in the off-on cue condition was probably eliminated by the appearance of red circle following the offset of the red circle.

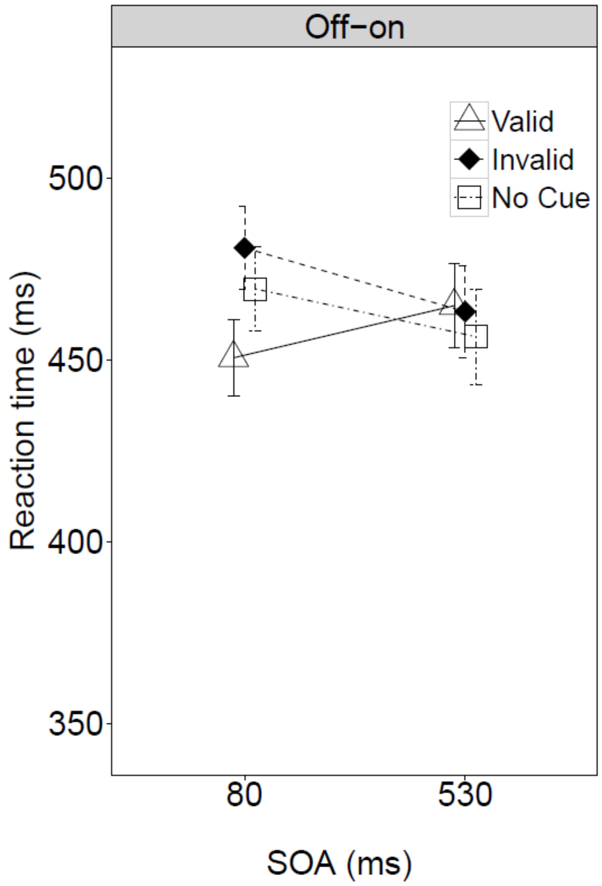


Figure 6.5. The adjusted mean RTs (ms) of the condition of off-on cue in Exp. 2 returned from the corresponding the fitted model for RT (Model 5). Error bars represent the 95% confidence intervals of the adjusted means.

In addition, in the double-cueing paradigm in Exp. 4B, Cue 2 appeared to work effectively in attracting attention to the location of the cue. Further, attention might stay at the location of Cue 2 for a long period, resulting in a small and non-significant IOR at the cue location. The effectiveness of Cue 2 in attracting attention in Exp. 4B but not in Exp. 4A could be explained by the expectation of observers for target onset after Cue 2 in Exp 4B.

6.4 Physical characteristics

The on-off cue in Exp. 2 probably attracted attention as effectively as the off-on cue if we take cue-target discriminability into account. It has been suggested that when cues and targets have a similar visual appearance, facilitation is absent (McAuliffe & Pratt, 2005; Pratt, Hillis, & Gold, 2001). Since the cue and target in the on-off cue condition have the same shape, size and luminance, they were closely matched in visual appearance. Participants would respond to a green circle (i.e., a target) appeared in the periphery as soon as they saw it but they would refrain from responding if it was a red circle (i.e., a cue). Responses to a target appeared shortly after the cue would be slowed down regardless the valid or invalid location because it was still the refraining period. It is possible that the cue actually attracted attention to the cue and then the refraining period began and may masked or cancel the facilitatory effect brought by the cue at the cue location, which results in no facilitation. However, because the discriminability between cues and targets was more obvious for the off-on cue, participants were not refraining from making responses (indicated by the no-cue condition) and results in facilitation. However, the process of refraining from making responses faded out over time. Therefore, a similar physical appearance between the cue and target may result in the absence of facilitation for the short SOA.

Exp. 3A and3B showed that when the manipulation of the physical characteristics of the cue and/or target did have effects on the performance of target detection, the effect was stronger when cue and target appeared at the same spatial location than when they appeared at different locations. This suggests that the spatial relationship between cue and target plays a role in the effect of the physical characteristics of the cue and/or target.

6.5 Implications

Previous research indicated that in detection tasks, facilitation is hard to observe whereas IOR is an extremely robust effect to find (see, e.g., Collie, Maruff, Yucel, Danckert, & Currie, 2000; Mele, Savazzi, Marzi, & Berlucchi, 2008; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1995). The results of experiments in this thesis strongly support this finding. Specifically, when the experiment included only single and on-off cueing, facilitation for the short SOA was not found whereas IOR was consistently found. Nevertheless, the absence and presence of facilitation and IOR can be affected by cue type (off-on cue) and the number of cues (double cueing). The random effects of the mixed models explained sufficient variance across subjects. This improved the estimates of the fixed effects because inherent noise from different individuals was controlled, suggesting individual differences in target detection.

6.6 Limitations

The use of an eye tracking device is recommended to control the eye gaze for both overt and covert attention tasks. It is known that foveal processing of stimuli is faster and more precise than peripheral processing. Therefore, the differences in performance between conditions might be due to the differences in foveal and peripheral processing rather than the effect of cue in the context of this thesis. If without the eye movement control, Chica et al. (2014) suggested that it is of great importance to ask participants to keep their eye at the fixation. They added that since eye movements have a long latency (approximately 100-300 ms), if not controlling fixation, a short SOA can be helpful so that assumedly participants do not have enough time to move eyes to the cue location. In all experiments I presented a fixation cross and instructed participants to fix their eye at the cross at the centre throughout the whole experiment. However, the short SOA I used mostly was 100 ms, which might not be short enough to reduce the possibility of eye movement. After all, the plausible suggestions that compensates for the absence of eye tracking can only reduce the influence of eye movement but not strictly and accurately control the effect of eye movement. Therefore, the lack of eye movement control is the limitation of this thesis and a problem to fix in the future work.

In addition, this thesis only explored facilitation and IOR in the COVAT paradigm, which is specifically designed for investigating covert and exogenous attention. Although using the similar paradigm (the COVAT paradigm) can easily control irrelevant factors and is simpler to compare results between experiments, the findings from these experiments were confined to limited context, that is, the COVAT with two target locations.

6.7 Future Directions

For experiments with single on-off cueing, facilitation was found in Exp. 4A and 4B but not in other experiments (i.e., Single on-off Exps). I hypothesised that in Exp. 4A, because of the temporal overlap of cues and targets between trials, participants had to process the target location to distinguish targets from cues. However, in other experiments on single on-off cueing, participants only needed to detect the occurrence of targets without knowing the target location so the response times were similar regardless of the target location. After blocking the single and double cueing in Exp. 4B, there should have been no temporal overlap of cues and targets between trials. However, I still found facilitation in the single-cueing condition. It is possible that the temporal overlap of cues and targets can not only occur between trials but also between blocks since the blocks of single and double were presented in alternation. In order to test this possibility, blocks of single and double cueing should be presented in separate sessions in a further experiment.

This thesis only investigated the characteristics of facilitation and IOR in the paradigm of COVAT, which is particularly for studying covert and exogenous attention. n addition, this thesis studied the characteristics of location-based IOR. Future work may use paradigms of different tasks to study different kind of attention such as endogenous attention and the characteristics object-based IOR.

Future work may investigate the individual differences in facilitation and IOR. For example, it is possible that people who are more sensitive to the peripheral visual field will have greater facilitation, such as professional drivers who need to stay alert to notice everything approaching him from not only the central but also the peripheral visual field.

In terms of measurements, the current experiments only measured simple reaction times and error rates. Future work may employ additional methods such as eye tracking, or neurophysiological methods such as EEG to study facilitation and IOR and reveal more detailed aspects of these two effects.

There is possible application of off-on cues. In Exp. 2 I found that off-on cue work effectively in terms of capturing covert attention. Furthermore, the off-on cue worked as effective as a cue overlapping in time with the target that can hold the attention to produce long facilitation. This may be applied to advertisements in order to attract the attention of viewers and therefore potential customers.

6.8 Conclusion

This thesis investigated the effect of physical characteristics of cues and targets and double cueing on facilitation and IOR. In Exp. 1 aimed to examine the cue-target discriminability by manipulating the novelty of cues and targets. I found IOR but no facilitation. In addition, the cue-target discriminability did not affect the IOR, which was in line with the conclusion suggested by Pratt and colleagues (2001). Exp. 2 aimed to examine the effect of presenting onset and offset cues on facilitation and/ or IOR in different sequences of appearing and disappearing cues by using on-off and off-on cues. For on-off cueing, I found IOR but no facilitation. For off-on cueing, I found facilitation and no IOR for off-on cueing. This suggests that compared to on-off cues, off-on cues work more effectively in terms of capturing attention and that off-on cues can eliminate the robust IOR. In addition, for the short SOA, the cue delayed the target detection for on-off cues but not for on-off cues. Exp. 3A aimed to examine the effects of the cue and target the size of the cue and target on facilitation and IOR. IOR was found for both the small and large condition. Size did not affect IOR. Facilitation was not found for either the small or large condition and instead, an early IOR was found for the short SOA in the small size condition. Exp. 3B aimed to examine the effect of changes in cue size on facilitation and IOR, with either static cues similar to Exp. 3A or dynamic cues I found no facilitation but observed IOR for all the conditions. Greater IOR was found with small cues compared to large cues in the static cue condition. In Exp. 4A and Exp. 4B I used a double-cueing paradigm. By systematically varying SOA-D and the relative location between the cue and target I studied the characteristics of facilitation as well as IOR. No matter whether single and double cueing were intermixed or blocked, facilitation and IOR was found for the single-cueing condition, although not for double cueing. I speculate that the occurrence of facilitation for single cueing may be due to the temporal overlap of cues and targets between trials and blocks. The results for double cueing in Exp. 4A showed that IOR was found at more than one location, that the most recently cued location produced the strongest IOR, and that IOR accumulated at the same location. When single and double cueing is blocked, the second cue started generating facilitation and producing weaker IOR for short and long interval between the second cue and targets, respectively. These results indicate that the second cue works effectively in terms of attracting attention, which is possibly due to the expectation of observers for target onset after the second cue.

This thesis strongly supports the finding in previous research that in detection tasks facilitation is more difficult to occur whereas IOR is a robust effect (see, e.g., Collie, Maruff, Yucel, Danckert, & Currie, 2000; Mele, Savazzi, Marzi, & Berlucchi, 2008; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1995). This was observed when the experiment included only single and on-off cueing. Nevertheless, I found that the absence and presence of facilitation and IOR can be affected by the cue type and the number of cues. That is, for cue type, off-on cue triggered facilitation for the short SOA but eliminated IOR for the long SOA. For the number of cues, when only two cues preceded targets in a block, the second cue generated facilitation for short SOA between second cue and target and produced weaker IOR for long SOA between second cue and target, compared to when either one or two cues preceded targets in a block. The random effects of mixed models explained sufficient variance across subjects to improve estimates of facilitation and IOR and variability was mainly due to individual mean RTs (random intercepts) across conditions.

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Appendix A

The output of GLMM of Experiment 1

cue.n1: repetitive cue; trg.n1: repetitive cue; SOA1: 100 ms; validity 1: valid.

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ cue.n * trg.n * SOA * validity + (0 + SOA + validity | s)
+
    (1 | cue.name) + (1 | trg.name)
   Data: rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid
 30540.8  30688.7 -15245.4  30490.8     2721

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.5931 -0.6119 -0.0865  0.4847  5.6328

Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 trg.name (Intercept) 209.87114 14.4869
 cue.name (Intercept) 206.75615 14.3790
 s        SOAX100     316.36306 17.7866
          SOAX800     216.62752 14.7183   0.75
          validity1    24.03145  4.9022  -0.26  0.29
 Residual               0.02643  0.1626
Number of obs: 2746, groups:  trg.name, 129; cue.name, 129; s, 11

Fixed effects:
                             Estimate Std. Error t value Pr(>|z|)
(Intercept)                  408.1994    11.1696   36.55 < 2e-16  ***
cue.n1                         1.9024     8.6601    0.22  0.82612
trg.n1                        -1.5274     8.9359   -0.17  0.86428
SOA1                          -0.9877     3.9134   -0.25  0.80073
validity1                     10.8183     3.4114    3.17  0.00152 **
cue.n1:trg.n1                  1.0964     1.7901    0.61  0.54025
cue.n1:SOA1                   -0.1989     1.8012   -0.11  0.91205
trg.n1:SOA1                    0.4554     1.7969    0.25  0.79993
cue.n1:validity1               0.1417     1.8051    0.08  0.93743
trg.n1:validity1               2.1560     1.8129    1.19  0.23434
SOA1:validity1                -8.5427     1.8178   -4.70 2.61e-06 ***
cue.n1:trg.n1:SOA1            -1.1050     1.8094   -0.61  0.54138
cue.n1:trg.n1:validity1       -0.3932     1.8120   -0.22  0.82823
cue.n1:SOA1:validity1         -0.6159     1.8197   -0.34  0.73502
trg.n1:SOA1:validity1          0.1999     1.8093    0.11  0.91203
cue.n1:trg.n1:SOA1:validity1  -0.7141     1.8068   -0.40  0.69267
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The output of GLMM of Experiment 2

flicker1: on-off cue; SOA1: 80 ms; validity1: valid; validity2: invalid.

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
```

```
Formula: rt ~ flicker * SOA * validity + (1 + flicker + SOA + validity |
s)
   Data: rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid
110604.6 110804.8 -55274.3 110548.6     9405

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.2636 -0.6229 -0.1437  0.4302  6.1969

Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 s        (Intercept) 475.87044 21.8145
          flicker1     82.27213  9.0704   0.17
          SOA1         17.28947  4.1581   0.10  0.34
          validity1    33.50928  5.7887  -0.24  0.19 -0.14
          validity2    60.62306  7.7861   0.13  0.08 -0.01 -0.54
 Residual               0.04269  0.2066
Number of obs: 9433, groups:  s, 20

Fixed effects:
                        Estimate Std. Error t value Pr(>|z|)
(Intercept)             452.7554     3.9828  113.68  < 2e-16 ***
flicker1                -11.5372     2.5765   -4.48 7.54e-06 ***
SOA1                     12.9055     1.6185    7.97 1.54e-15 ***
validity1                 0.5657     2.0145    0.28 0.778863
validity2                 0.1992     2.3215    0.09 0.931616
flicker1:SOA1            10.1804     0.8483   12.00  < 2e-16 ***
flicker1:validity1        7.0558     1.1305    6.24 4.34e-10 ***
flicker1:validity2       -7.5905     1.1488   -6.61 3.92e-11 ***
SOA1:validity1           -4.2707     1.1546   -3.70 0.000217 ***
SOA1:validity2           11.1143     1.1715    9.49  < 2e-16 ***
flicker1:SOA1:validity1   5.6135     1.1795    4.76 1.94e-06 ***
flicker1:SOA1:validity2   5.0725     1.1760    4.31 1.61e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The output of GLMM of Experiment 3A

Size1: size small; SOA1: 100 ms; validity1: valid.

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ size * SOA * validity + (1 + size + SOA | s)
   Data: rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid
 41272.2  41366.2 -20621.1  41242.2     3876

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.4460 -0.5653 -0.0059  0.5793  4.0589

Random effects:
 Groups   Name        Variance Std.Dev. Corr
 s        (Intercept) 74.4653  8.6293
          size1        8.3447  2.8887    0.34
          SOA1        34.5307  5.8763   -0.24 -0.34
 Residual              0.0179  0.1338
```

```
Number of obs: 3891, groups:  s, 16

Fixed effects:
                     Estimate Std. Error t value Pr(>|z|)    
(Intercept)          357.5245     5.1966   68.80  < 2e-16 ***
size1                 10.6283     1.5487    6.86 6.76e-12 ***
SOA1                  -4.4395     3.3360   -1.33   0.1833    
validity1              9.1009     0.7717   11.79  < 2e-16 ***
size1:SOA1            -0.8582     0.7740   -1.11   0.2675    
size1:validity1        1.6061     0.7719    2.08   0.0375 *  
SOA1:validity1        -7.3937     0.7710   -9.59  < 2e-16 ***
size1:SOA1:validity1   1.9352     0.7733    2.50   0.0123 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The output of GLMM of Experiment 3B

CueType1: static; CueSize1: small; SOA1: 150 ms; validity1: valid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ CueType * CueSize * SOA * validity + (1 + CueType + SOA |
s)
   Data: rt.dat
Control: glmerControl(optimizer = "bobyqa")

      AIC       BIC    logLik  deviance  df.resid 
 245066.5  245251.1 -122510.3  245020.5     22552 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-4.1761 -0.6109 -0.1005  0.4700  7.5220 

Random effects:
 Groups   Name        Variance  Std.Dev. Corr     
 s        (Intercept) 169.98297 13.0378           
          CueType1      7.11177  2.6668  0.15     
          SOA1         28.67531  5.3549  0.04 0.10
 Residual               0.02396  0.1548           
Number of obs: 22575, groups:  s, 30

Fixed effects:
                                   Estimate Std. Error t value Pr(>|z|)    
(Intercept)                       3.801e+02  2.218e+00  171.41  < 2e-16 ***
CueType1                          4.679e+00  8.676e-01    5.39 6.93e-08 ***
CueSize1                         -5.120e-01  3.565e-01   -1.44  0.15095    
SOA1                             -2.845e+00  1.571e+00   -1.81  0.07006 .  
validity1                         5.884e+00  3.579e-01   16.44  < 2e-16 ***
CueType1:CueSize1                 1.690e-01  3.567e-01    0.47  0.63559    
CueType1:SOA1                     4.767e-05  3.547e-01    0.00  0.99989    
CueSize1:SOA1                    -7.700e-01  3.593e-01   -2.14  0.03210 *  
CueType1:validity1                1.055e+00  3.571e-01    2.96  0.00312 ** 
CueSize1:validity1                4.183e-01  3.555e-01    1.18  0.23932    
SOA1:validity1                   -7.044e+00  3.577e-01  -19.69  < 2e-16 ***
CueType1:CueSize1:SOA1            1.622e-02  3.580e-01    0.05  0.96386    
CueType1:CueSize1:validity1       2.040e-01  3.547e-01    0.58  0.56529    
CueType1:SOA1:validity1          -3.296e-01  3.558e-01   -0.93  0.35419    
```

```
CueSize1:SOA1:validity1          -8.214e-01  3.553e-01   -2.31  0.02079 *
CueType1:CueSize1:SOA1:validity1 -6.517e-01  3.596e-01   -1.81  0.06994 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The output of GLMM of Experiment 4A

Single Cueing

SOA1 = 100 ms; Xback1 = valid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) [glmerMod]
 Family: Gamma  ( identity )
Formula: rt ~ SOAs * Xback + (1 + SOAs | s)
   Data: s.rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid
 51791.1  51842.7 -25887.5  51775.1     4710

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.3801 -0.6294 -0.1267  0.4715  6.0682

Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 s        (Intercept) 139.03801 11.7914
          SOAs1        30.28833  5.5035  0.18
 Residual               0.02871  0.1694
Number of obs: 4718, groups:  s, 20

Fixed effects:
             Estimate Std. Error t value Pr(>|z|)
(Intercept)  364.0531     4.8622   74.87   <2e-16 ***
SOAs1         -4.4681     2.3135   -1.93   0.0534 .
Xback1         0.3099     0.8461    0.37   0.7142
SOAs1:Xback1 -10.3252     0.8411  -12.28   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Double Cueing

SOA1 = 11 ; SOA2 = 18 ; SOA3 = 81

Xback1 = one-back; Xback2 = two-back ; Xback3 = double valid ; Xback4 = double invalid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
```

```
 Family: Gamma  ( identity )
Formula: rt ~ SOAs + Xback + (0 + SOAs | s) + SOAs:Xback
   Data: d.rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid 
 50223.3  50345.6 -25092.6  50185.3     4603 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-3.5178 -0.6048 -0.1075  0.4667  7.5858 

Random effects:
 Groups   Name    Variance  Std.Dev. Corr     
 s        SOAsdss 209.87793 14.4872           
          SOAsdsl 143.32083 11.9717  0.43     
          SOAsdls 131.36507 11.4615  0.77 0.55
 Residual           0.02703  0.1644           
Number of obs: 4622, groups:  s, 20

Fixed effects:
             Estimate Std. Error t value Pr(>|z|)    
(Intercept)   353.069      6.516   54.18  < 2e-16 ***
SOAs1          -5.816      3.115   -1.87  0.06190 .  
SOAs2          10.860      3.377    3.22  0.00130 ** 
Xback1         -2.768      1.356   -2.04  0.04127 *  
Xback2          7.166      1.381    5.19 2.11e-07 ***
Xback3          4.305      1.391    3.09  0.00198 ** 
SOAs1:Xback1   -2.647      1.884   -1.40  0.16010    
SOAs2:Xback1    9.505      1.968    4.83 1.36e-06 ***
SOAs1:Xback2   -2.209      1.918   -1.15  0.24947    
SOAs2:Xback2  -11.164      2.013   -5.55 2.94e-08 ***
SOAs1:Xback3   -2.069      1.880   -1.10  0.27110    
SOAs2:Xback3   10.395      1.940    5.36 8.40e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The output of GLMM of Experiment 4B

Single Cueing

SOA1 = 100 ms; Xback1 = valid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ SOAs * Xback + (1 + SOAs | s)
   Data: s.rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid 
 51421.6  51473.3 -25702.8  51405.6     4734 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-3.3654 -0.6114 -0.1134  0.4565  6.9519 

Random effects:
 Groups   Name        Variance  Std.Dev. Corr 
 s        (Intercept) 126.61230 11.2522       
          SOAs1        24.34093  4.9337  -0.22
 Residual               0.02749  0.1658       
Number of obs: 4742, groups:  s, 20
```

```
Fixed effects:
              Estimate Std. Error t value Pr(>|z|)    
(Intercept)   348.9819     5.2582   66.37  < 2e-16 ***
SOAs1          -9.9258     2.0536   -4.83 1.34e-06 ***
Xback1          1.3549     0.7907    1.71   0.0866 .  
SOAs1:Xback1 -10.2566     0.7942  -12.91  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Double Cueing

SOA1 = 11 ; SOA2 = 18 ; SOA3 = 81

Xback1 = one-back; Xback2 = two-back ; Xback3 = double valid ; Xback4 = double invalid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ SOAs * Xback + (1 + SOAs | s)
   Data: d.rt.dat
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid 
 51006.4  51129.3 -25484.2  50968.4     4728 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-3.5764 -0.6119 -0.1100  0.4561  8.8730 

Random effects:
 Groups   Name        Variance  Std.Dev. Corr       
 s        (Intercept) 115.70801 10.7568             
          SOAs1        32.56286  5.7064  -0.10      
          SOAs2        41.08693  6.4099   0.07 -0.66
 Residual               0.02474  0.1573             
Number of obs: 4747, groups:  s, 20

Fixed effects:
             Estimate Std. Error t value Pr(>|z|)    
(Intercept)  348.5850     4.6276   75.33  < 2e-16 ***
SOAs1          2.1468     2.2044    0.97 0.330122    
SOAs2          7.1935     2.4756    2.91 0.003664 ** 
Xback1       -10.1252     1.2539   -8.07 6.75e-16 ***
Xback2        10.8338     1.3131    8.25  < 2e-16 ***
Xback3         1.9337     1.2872    1.50 0.133019    
SOAs1:Xback1  -0.6971     1.7381   -0.40 0.688344    
SOAs2:Xback1   6.1441     1.7524    3.51 0.000455 ***
SOAs1:Xback2   0.2932     1.7861    0.16 0.869612    
SOAs2:Xback2  -8.2573     1.7793   -4.64 3.47e-06 ***
SOAs1:Xback3  -4.2217     1.7000   -2.48 0.013014 *  
SOAs2:Xback3   9.0681     1.7586    5.16 2.52e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Single cueing for SOA 200 and 900 ms

SOA1 = 200 ms; Xback1 = valid

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approx
imation) ['glmerMod']
 Family: Gamma  ( identity )
Formula: rt ~ SOAs * Xback + (1 + SOAs + Xback | s)
   Data: s.rt.dat29
Control: glmerControl(optimizer = "bobyqa")

     AIC      BIC   logLik deviance df.resid
 20505.2  20566.2 -10241.6  20483.2     1872

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.1018 -0.6182 -0.1576  0.3591  6.6534

Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 s        (Intercept) 264.92364 16.2765
          SOAs1        64.98731  8.0615  -0.19
          Xback1       47.29339  6.8770  -0.33  0.13
 Residual               0.03043  0.1744
Number of obs: 1883, groups:  s, 20

Fixed effects:
             Estimate Std. Error t value Pr(>|z|)
(Intercept)   347.684      7.565   45.96  < 2e-16 ***
SOAs1          -3.704      3.296   -1.12 0.261128
Xback1          2.872      2.878    1.00 0.318305
SOAs1:Xback1   -4.452      1.256   -3.54 0.000394 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```